INTERNATIONAL ENERGY AGENCY

ENERGY TO 2050

Scenarios for a Sustainable Future

OECD

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six* of the OECD's thirty Member countries. The basic aims of the IEA are:

- to maintain and improve systems for coping with oil supply disruptions;
- to promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations;
- to operate a permanent information system on the international oil market;
- to improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use;
- to assist in the integration of environmental and energy policies.

** IEA Member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. The European Commission also takes part in the work of the IEA.*

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and Slovakia (28th September 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

FOREWORD

Analysing the intersection between energy and climate change mitigation issues requires the adoption of a very long-term perspective. Energy infrastructure takes a very long time to build and has a useful life often measured in decades. New energy technologies take time to develop and even longer to reach their maximum market share. Similarly, the impact of increasing concentrations of greenhouse gases from human activities develops over a very long period (from decades to centuries), while policy responses to climate change threats may only yield effects after considerable delay. Analysis that seeks to tackle these issues must take a similarly long term view – looking ahead at least thirty to fifty years.

Unfortunately, analysis of such time frames is an uncertain science. The future is by definition unknown and cannot be predicted. While over time horizons of ten years the inertia of the energy/economy system is so strong as to leave little room for change, over longer periods, the future will almost certainly look different than the present.

Projections and scenario analysis can help us to understand the factors that might affect the future of the energy economy. These include uncertain future technological developments, economic growth, government policies and a maze of product introductions and consumer responses that can, over the long run, fundamentally change how and why we use energy.

The IEA has conducted considerable work projecting future trends: our World Energy Outlook has long been recognised as the authoritative source for projections of global energy supply and demand, as well as future energy investments and carbon dioxide emissions. The World Energy Outlook contains reference and alternative policy scenarios reflecting that outcomes will depend on what new policies are undertaken by governments. However, the time-horizon of World Energy Outlook projections focuses on a thirty year time period in which the uncertainty that could result from unpredictable factors is relatively small. Past this time horizon, these factors become increasingly important and the way these long-term projections can be used fundamentally changes.

With this book, the IEA explores a longer time horizon using two types of long-term scenarios: "exploratory scenarios" and "normative scenarios". Exploratory scenarios are based on the correct identification of a few critical uncertainty factors and are designed to explore several plausible

future configurations of the world, based on different expectations of technical and/or policy developments over the near- to medium-term. Normative scenarios are a developed to evaluate "how" a specific outcome can be reached. They are designed on the basis of a set of desirable features (or "norms") that the future world "should" possess (of course, reflecting a bias of the agent elaborating the scenarios). The exercise then consists of tracing backwards a viable path from such an outcome to today – pointing the way to reaching that desirable future. This type of scenario is inherently policy oriented and prescriptive, i.e. it assumes that appropriate policy actions can shape a future in the desired image, and is designed to identify the policy actions required. Such work requires substantial effort because several scenarios (each with its own internally consistent and plausible chains of events or storyline) have to be developed in order to analyse how uncertainty factors play into future development paths.

The results from these and other such scenarios can help identify robust strategies to minimize costs of both economic dislocations and environmental damage in the development of future energy paths, in turn, assisting in promoting better policy choices in the energy sector. While the scenarios depicted here do not represent a consensus view of the IEA member countries – and equally, are not likely to come to pass in the precise way they are outlined, the methodology which supports them provides a useful tool for IEA country governments to assess and, when appropriate, consider redirecting their energy and environment policies.

Claude Mandil
Executive Director

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BACKGROUND

"When it is urgent is already too late". Talleyrand

"Necessity is nothing more than the lack of foresight". H. de Jouvenel (2000)

What are Scenarios and why they are Useful?

Analysing the intersection between energy and issues of climate change mitigation requires the adoption of a long-term perspective. Energy infrastructure takes time to build up and has a useful life that for some plants is measured in decades. New energy technologies take time to develop and even longer to reach their maximum market share. Increasing concentration of greenhouse gases from human activities affects ecosystems and global climate over a long period – from decades to centuries. Policy responses to the threats of climate change manifest effects on emissions that can be appreciated after an often considerable delay. An analysis that seeks to tackle energy and environmental issues needs to look ahead at least to the next thirty to fifty years.

Such a long-term perspective must come to terms with the concept of uncertainty and with the limitations of our knowledge. The future is by definition unknown and cannot be predicted. It is not something predetermined that we simply ignore. How it unfolds is to some extent determined by the course of actions we decide to take.

For this reason we need to look at the future and its uncertainties in an articulated fashion, beyond the simple assumption that present trends will continue tomorrow. Over time horizons of five to ten years the inertia of the energy/economy system is so strong as to leave little room for change, but over longer periods the future will almost certainly look different.

Basing our long-term strategic decisions on the assumption of continuation of present trends presents risks: what if things do not turn out to be as expected? That possibility must be taken into account if we want to have a contingency plan at all. In particular, we need to contemplate the possibility that some critical variables, the ones that have the potentially largest impact in the success of our plan, take a different course. What do we do in that case? And, more generally, what strategy or course of action would maximise our chances of success in a wide range of different situations?

Furthermore, even assuming continuation of present trends we are often obliged to see that those trends may not necessarily lead to desirable outcomes. Trends may be unsustainable under a number of aspects. Developing through logical reasoning the final consequences of those trends may point to some clear dangers down the road. Should we not then try to steer clear of those dangers by modifying our trajectory? The intellectual exercise of looking farther into the future can be extremely useful to provide early warnings, in time for us to engage the possibility of actually modifying our behaviour.

These facts lead to two important considerations:

- over the long term a thorough understanding of the main elements of uncertainty is the basis for any strategic planning;
- over the longer term an additional element of freedom comes into play inasmuch as the future can be shaped by political will.

Usually, the way the future is explored is through scenarios. These, in simple terms, are conjectures about what could happen in the future based on our past and present experience of the world. Hence, to build scenarios, soft or hard data about past and present trends are a necessary ingredient. Plausible conjectures about how these trends may further evolve in the future are the other element. Unless one believes fatalistically that the future is predetermined, the fact that all scenarios remain inherently speculative in nature diminishes neither their role nor their usefulness, which is mainly to assist in decision-making by offering the possibility of identifying problems, threats and opportunities. By examining an internally consistent and rational chain of events and trends that may follow from present actions, they allow a better assessment of alternative policies. For this reason the exploration of the future is often referred to in the literature as "scenario planning".

This type of exercise can be conducted at different scales and with different time horizons in contexts that range from the trivial day-to-day planning, to the strategic planning of an enterprise, to longer term plans for a country’s infrastructure development. At the lower end of the scale we are used to performing this scenario-development process without giving it much thought: at the high end, considerable time and resources (both human and equipment) may be required.

While it is clear that scenario work at the scale needed to analyse global energy and environment futures is likely to require time and intellectual resources, we should not be satisfied with producing and using only one type of scenario.

Different Types of Scenario

The type of scenario with which we are most familiar is the reference scenario of the forecasting type, which assumes the continuation of historical trends into the future and that the structure of the system remains unchanged or responds in predetermined forms.

This type of scenario is often referred to as a "business-as-usual (BAU) scenario". In consideration of the inertia of many of the systems under investigation, a short to mid-term forecast is often viewed as a scenario with a high probability associated to it. But when projected over a longer time horizon those trends may turn out to be extremely unlikely. The system may be, for instance, close to a turning point, or display previously undetected chaotic features. Some of the underlying factors that drive an energy/environment system (including, for instance, technological development, degree of openness of markets, social structures, environmental values held by the people, and so on) are much less predictable. However, over periods of 30 to 50 years, it is precisely these factors that are the most important. And it is in this medium-long-term horizon (30-50 years out), that many of the critical environmental issues become most pertinent. For example, climate change and the growth in emissions that lead to global warming have their impact over a period of 100 years – with the near term path only critical in how it affects longer-term, cumulative emissions. Therefore, over the long run it is difficult and risky to base one's future strategy uniquely on BAU scenarios and forecasts. Policy scenarios, designed to analyse the impact of introducing a new policy in a context that in every other respect reflects the continuation of present trends, often present many of the same limitations of BAU scenarios.

Exploratory scenarios, on the other hand, are designed to explore several plausible future configurations of the world. The purpose is of identifying across those scenarios the most robust strategies from the standpoint of the subject that undertakes the exploration. From the point of view of designing strategic action, it is often plausible scenarios running counter to conventional wisdom that are the most fruitful.

Identifying factors that affect GHG emissions paths over a 50-year period would be helpful in making policy choices. Similarly, environmental implications of new technologies may demonstrate critical path dependencies over a similar time frame – particularly in the energy sector, where capital stock turnover of large-scale power plants is usually measured in terms of 30 or more years. Exploratory scenarios thus can:

- help scientists and policy analysts to identify the main dimensions and drivers that shape those future worlds;
- help them to explore and understand the dynamic links among the main drivers and to assess their relative importance (in terms of potential impacts) as sources of uncertainty;
- allow a more systematic and full appreciation of the uncertainties that lie ahead in the energy and environment domain.

Exploring and identifying the uncertainties over such factors becomes critical in order to formulate "least regret" strategies that, given the uncertainty, produce the fewest drawbacks, if not the greatest benefits. Those strategies that minimize regrets over different possible outcomes can then be valid candidates for implementation. The potential implications for policy of this type of scenarios are clear. In this case scenarios are used in their "explorative" mode, for strategic planning purposes.

This type of work, however, requires substantial effort because several scenarios, and as many internally consistent and plausible chains of events or storylines, have to be developed on the basis of the alternative outcomes of the critical uncertainty factors identified.

To a large extent, agents (individuals, businesses) and societies have the capacity to shape their own future, and often have the means to implement their vision. The task then becomes one of identifying the necessary steps and the roadmap to get there: in the case of energy and the environment steps refer to policies needed, R&D policy, and so on. In this second case scenarios are of the "normative" type, and the path to their implementation is outlined through a "back-casting" process.

Normative scenarios can be designed on the basis of a set of desirable features (or "norms") that the future world should possess according to the agent elaborating the scenario. This type of scenario is inherently policy oriented and prescriptive. That is to say such scenarios assume that policy actions can shape a future in the desired image, and they are designed to identify the policy actions required.

Objectives and Purpose of this Study

IEA Member governments have collectively recognised that the future under a "business-as-usual" scenario is undesirable. The IEA Statement on Sustainable Development puts it clearly: "Are we on a sustainable path? Not

unless we make considerable changes." The elements of unsustainability are unambiguously outlined in the two most recent volumes of the World Energy Outlook: the WEO 2002 points to a considerable increase in greenhouse gas emissions – well exceeding the Kyoto targets. WEO 2001 Insights indicates that security of supply issues are also a matter for considerable concern; while fuel resources are more than adequate to cover demand for the next 30 or more years, those resources are concentrated in a limited set of countries, many of which are subject to instability. Recognising that a sustainable and secure future is unlikely to unfold unless policy intervention is taken, there is a clear role for additional scenario tools and approaches – covering the longer-term, and looking also at a variety of strategic issues and policy actions to bring about desirable outcomes.

The work presented here intends to provide an experimental introduction to different types of scenarios, in the effort to complement the array of available tools, and to address specific aspects of the analysis of the energy and environment intersection in the longer term. In this sense it is both different from – and complementary to – that of the WEO. Broadening the suite of tools to other types of scenarios is recognised as an important step to establish a basis for more strategic thinking even for an organization like the IEA. The objectives pursued are manifold:

- to strengthen the analysis of energy and environment issues over the long term by aiding in the correct identification of the main drivers of change and in understanding the dynamic links among these drivers;
- to clarify the relationship between short-term and longer-term objectives, and how they change over time under the pressure of long term trends and factors;
- to ensure greater consistency between long-term policy objectives and policies to bring them about, particularly with respect to the planning of the policies and their impact over time.

Outline of Book Contents

Energy and environment scenarios have been developed by a variety of groups: for example, the Intergovernmental Panel on Climate Change (IPCC), the International Institute for Applied Systems Analysis (IIASA), the Shell company, and others are often cited. Some have been developed as simple storylines while others have been represented with the aid of a quantitative framework such as a mathematical model. A review of recent literature on energy and environment scenarios is provided in chapter 1

together with a methodological introduction to scenarios and some definitions. Two types of scenario are discussed in particular: "exploratory scenarios" and "normative scenarios". A systematic characterisation of the scenarios examined in the literature is provided together with a critique, to arrive at the identification of gaps and areas that need further work.

Based on this critique, new scenarios of both types are developed to provide an illustration of how they can be used - in the context of an intergovernmental agency like the IEA - to broaden our understanding of the challenges posed by sustainable development in the areas of energy and the environment.

Chapter 2 describes the methodology followed to build three exploratory scenarios looking out to 2050 and develops them in the form of narrative storylines. The stories are fleshed out around a set of key drivers considered as the areas in which the most relevant uncertainties for the energy/environment system can be found. As a result three different images of the world are given and, consistent with those images, implications are suggested for the energy technologies that are likely to emerge in each of those worlds.

Chapter 3 develops a hypothetical normative case scenario based on a set of desirable characteristics (or "norms") that the future world in 2050 should possess. The criteria used to select these characteristics, and the process followed to express these characteristics in metric form (i.e. as quantitative targets), are illustrated. To help appreciate the scale of the challenges involved in bringing about such a scenario, a quantitative framework is provided. To this end, however, rather than simulating this scenario with the use of a model, an existing scenario has been used and modified to fit the desired image.

The challenges in implementing any future vision of the world that requires changing trends are enormous – and implementing the hypothetical scenario outlined here would be no less difficult. However, the key is not whether this scenario is "correct" or "most desirable" but rather, what it tells us about future policy choices. By highlighting the implications for policy action, including for technology development, energy and climate change mitigation, we may better understand how our current actions affect the future, and work toward a future that is more in keeping with our collective goals.

Finally, the conclusions and implications, including in the domains of policy analysis and strategic planning, as well as implications for further analysis, are summarised in the final section.

LONG TERM ENERGY AND ENVIRONMENT SCENARIOS: THE LITERATURE

This chapter starts with a brief description of the process of scenario building, defines some elements for a taxonomy of scenarios and briefly discusses the use of models as a tool for scenario representation or testing. A review of recent work in energy and environment scenarios is then provided, covering different approaches and tools. At the end a critique of these scenarios is developed, stressing differences and commonalities with respect to purpose, approach, drivers identified, major risks and uncertainties, and highlighting relevant elements and methodological aspects that might serve as a guide in any future construction of energy/environment scenarios.

General Methodological Aspects

Basic Definitions

Definitions of scenarios abound in the literature. According to the definition given by Peter Schwartz in his book "The Art of the Long View" (1991):

"Scenarios are a tool for helping us to take a long view in a world of great uncertainty. The name comes from the theatrical term "scenario" – the script for a film or play. Scenarios are stories about the way the world might turn out tomorrow, stories that can help us recognize and adapt to changing aspects of our present environment. They form a method for articulating the different pathways that might exist for you tomorrow, and finding your appropriate movements down each of those possible paths. Scenario planning is about making choices today with an understanding of how they might turn out.

In this context the precise definition of "scenario" is: a tool for ordering one's perceptions about alternative future environments in which one's decision might be played out. Alternatively: a set of organized ways for us to dream effectively about our own future. Concretely they resemble a set of stories, either written out or often spoken. However, these stories are built around carefully constructed "plots" that make the significant elements of the world scene stand out boldly. This approach is more a disciplined way of thinking than a formal methodology."

Scenarios therefore describe hypothetical processes, sequences of events that could develop over a period of time.

The above definition is in clear contrast with any idea of "prediction", as the future cannot be predicted with certainty. Furthermore, it is radically different from the idea of traditional business forecasting, inasmuch as scenarios present alternative images of the future, rather than merely projecting the trends of the present. As Ged Davis (1998), of Shell International puts it:

"Many have tried to understand the future purely through prediction, even though the record to date is poor. Forecasters extrapolate from the past, imposing the patterns they see in the past onto the future, and tend to neglect the oft quoted statement that 'a trend is a trend is a trend until it bends'. And it is the bends that are generally of most interest to us because it is the bends that carry the most risk or offer the greatest opportunities."

Useful as they are, forecasts present a fundamental danger: they give us the illusion of certainty and leave us ill equipped to understand uncertainty and risk. In fact one of the most useful characteristics of scenarios is that they are explicitly designed to explore, and thus integrate, radical departures from trend, breakdowns in the system, technological breakthroughs, major shifts in human behaviour or changes in institutional rules.

"The end result [of a scenario exercise] is not an accurate picture of tomorrow, but better decisions about the future." (Schwartz, 1991)

Historically, scenarios started to be developed after World War II, as an intellectual exercise for military strategy purposes, but were soon adopted by some multinational companies such as Royal-Dutch Shell for strategic decision making. In the last 15 years they have become more widespread as a tool to aid in planning and policy decision making by governments and ministries, in a variety of areas: from research to public health, from urban planning and transport to energy infrastructure.

Developing a Scenario – Key Elements

A fundamental requirement of scenarios is that they be internally consistent, logical and plausible constructs of how the future might unfold. Furthermore, scenario building is an inherently interdisciplinary process, because it needs to take into account the many dimensions of the same problem.

Scenarios need to integrate long-term phenomena (including demographic, technological or ecosystem trends) with shorter-term phenomena (like

inflation or spikes in oil prices). And as mentioned earlier, they need to take into account possible departures from trend (De Jouvenel, 2000). Scenarios should also possess the capability of challenging users' mental maps, because that is when a true possibility to learn exists (Davis, 1998).

The process of scenario building is a complex analytical exercise. Five main steps are discernible:

- Define the problem and its horizon or isolate the decision that needs to be made.
- Gather information, expert opinion and past data on the system under investigation and build a coherent system that includes all relevant actors and agents, including the factors and links (both quantitative and qualitative) between them.
- Identify the key factors that would affect decisions and separate predetermined or unavoidable factors and trends from those that are highly uncertain or depend on will.
- Rank these factors by importance for the success of the focal issue (defined in step 1) or by uncertainty and identify the two or three factors or trends that are most important and most uncertain. These will represent the main axes along which scenarios will differ and will be characterised. Predetermined elements/factors will remain unchanged in all scenarios.
- Flesh out the scenarios in the form of consistent narratives or "stories".

The next logical step is to examine the implications of the various scenarios and translate them into clear strategic choices. Different choices can at that point be tested for robustness/resilience against the scenarios outlined.

Taxonomy

The scenario process outlined above corresponds, strictly speaking, to that of so-called *"exploratory"* or *"descriptive"* scenarios, built for the purpose of exploring a range of outcomes and analyse their implications for strategic decision-making.

The main value added in exploratory scenarios lies in the fact that they help prepare for turns of those events that are plausible and entirely possible without representing a straight-line continuation of past and present trends. They are particularly useful in proximity to bifurcations,

especially when a hint of such a situation takes shape in present day phenomena. And they can help enormously to accelerate and calibrate the response to new developments (both positive and negative ones).

Scenarios, however, can also be *"normative"* or *"strategic"*. In this case the perspective is changed: a "desirable" vision of the future, or a goal in the future, is outlined. What is considered "desirable" clearly depends on the general objectives of the individual or group elaborating the scenario. An example could be a sustainable scenario characterised by stabilisation of GHG concentrations at 450 ppm by the end of this century. These objectives are used as a point of departure from which to travel backward and identify the conditions that must be fulfilled or measures to be taken at different stages along the path in order to implement that vision or achieve that goal. Typically, normative scenarios tend to work in a "back-casting mode".

This represents a critical change of perspective. It provides a useful mechanism to focus attention on several crucial elements: actions that must be taken and conditions that must be created at certain points in time in order to make the scenario achievable. The emphasis is on planning to achieve a certain result rather than on preparedness in responding to uncertain events. The attitude is more proactive, and policy intervention is a tool of choice.

Building a normative scenario requires rationalisation at the initial stage in order to define desirable characteristics of the future state of affairs, and to express them as measurable targets. Furthermore, the exercise stimulates formulation of critical questions, the recognition of uncertainties, the identification of bottlenecks and priority areas for policy action as well as for research and technological development.

While *"exploratory"* scenarios set the groundwork to describe what could happen, *"normative"* scenarios help decide what one could or should do, and hence are more concerned with action. In practise, normative scenarios of this type are rarely found in isolation, i.e. without previous analysis of what the future might bring (De Jouvenel, 2000; Greeuw et al., 2000).

Another common distinction is between *"qualitative"* and *"quantitative"* scenarios. The former are pure narrative stories describing how the future might unfold or the relationships internal to the system analysed, without the help of figures. The latter also give a numerical illustration of the evolution of key variables or indicators. Quantitative scenarios are often represented through the use of a model, but may be also illustrated through much simpler tools.

Box 1.1 Models: a Scenario Tool

Mathematical and statistical models can be used as a tool in long-term scenario analysis. Models and scenarios may be based on many of the same elements of information, especially with respect to past data and analysis of a system's internal relationships.

A model is an abstract representation of a system, described through a series of causal links and "accounting" identities among its elements. Its underlying basis is a theory of causal relationship among a set of variables relevant to the analyst. Theoretical models of these causal relationships are mathematically formalised and then can either be simulated numerically or estimated from historical empirical data through statistical methods.

Models are frequently used in policy simulations, where they not only permit analysis of causality and direction of change but also quantify the impacts of policy choices.

In a way a quantitative scenario is created whenever exogenous variables and parameters are fed into a model. In a restrictive interpretation, "trend projections" or "forecasts" can be seen as scenarios that assume a continuation of past and current trends into the future.

Models, however, have limitations. Notably they are deterministic, they have difficulties in addressing "surprises" and often give only an "incremental change" view of the future. Models exhibit difficulties representing some of the dynamic elements that characterise scenarios. They represent the inertia of energy systems fairly well, but do a poorer job representing the system in the longer term when elasticities change. Catastrophic developments, discontinuities and structural breakdowns are extremely difficult to take into account. Furthermore, many aspects of human and social behaviour, such as "values" or "institutional frameworks" can only be poorly represented (through proxy variables) in models.

Some of the limitations of models can in fact be addressed within the modelling approach itself, through the use of different model types, having different degrees of mathematical complexity and data intensity. However no single model is likely to be adequate for the purpose of analysing all aspects of economic/energy/environment scenarios, especially with a long-term focus. Rather, scenario exploration could be supported by a suite of models.

Narrative scenarios can more easily accommodate an interdisciplinary perspective and the complex interrelationship of a system than can quantitative models. However, policymakers are likely to be more interested in scenarios offering quantified, credible representations of policy measures and their impacts, and that say something about the time path of the system's response. Since a minimum level of quantification is useful to test the validity and consistency of the scenario, scenarios are often simulated with the use of modelling tools.

As a general criterion, however, because any given model can only represent and analyse a given specific system, the model used to simulate a certain scenario must be a good match for the scenario. The choice of the model(s) to quantify a scenario depends on the scenario to be illustrated and on the specific issues or uncertainties that a scenario tries to illuminate. Therefore, the level of aggregation of the model, and its analytical focus, must be adapted to the focus and purpose of the scenario. This criterion applies both to the representation of an exploratory scenario and to the simulation of a normative scenario.

In order to quantify an *exploratory* scenario, the storyline and its main drivers must be "transposed" into a set of characteristic "exogenous variables" and corresponding values in the chosen model, which is then run until it adequately represents the underlying story.

To represent a *normative* scenario, the desired characteristics of the future world can be expressed either as exogenous variables or as targets (often constraints) for the chosen model, depending on the characteristics considered. The results of the model runs may provide a time path for relevant variables as the system adapts to the planned vision, and useful insights on some of the limits or bottlenecks it is likely to run into on its way to achieving the targets.

Another type of scenario that is increasingly popular are policy scenarios, designed to analyse the impact of introducing a new policy in a context that in every other respect reflects the continuation of present trends. Scenarios of this type can be considered as a more restrictive subcategory under the general normative scenario category.

It is important to remember that the main function of scenarios is to help explore the main uncertainties lying ahead, by making them more explicit. Model quantification of scenarios by giving a more "precise" representation of a scenario may induce, especially in lay people, the

illusion of accuracy, which is counterproductive with respect to the purpose of a scenario exercise.

In the following review, we shall focus on scenarios and deal with models only when used to quantify a specific scenario.

Review of Recent Scenario Work

In this review, which does not claim to be exhaustive, we try to characterise scenarios on the basis of such elements as the purpose (exploratory vs. normative), the time horizon considered, the construction process and the type of tools used (qualitative vs. quantitative). The review starts with global scenarios and then analyses national scenarios, indicating wherever possible the main drivers and trends identified, and some of the quantitative elements (population and income growth, energy demand, technologies used, GHG emissions, resulting concentrations). In Appendix I an outline of each scenario is also provided.

Global Scenarios

Shell's Scenarios

Shell has long-standing experience in developing long-term energy scenarios as a tool for better business decision making: its first scenario that dared look out over 50 years was produced in 1995. Scenario planning started at Shell in the early 1970s, with the work of Pierre Wack, who was able to present Shell's board of directors with two scenarios – one titled "conventional wisdom" and the other titled "oil price crisis scenario". These were made available only months before the October 1973 oil crisis, thus preparing the company for that abrupt change. The company's ability to respond quickly resulted in enhanced profitability – and had the side effect of enshrining scenarios as part of the standard practice at Shell's Group Planning division. Over the years, Shell's planners have been involved in developing scenarios in collaboration with such bodies as the World Business Council for Sustainable Development and the Intergovernmental Panel for Climate Change.

In general the Shell scenarios are of the "exploratory" type, designed around "what if" questions, and written in the form of narratives for greater ease of communication. Quantitative indicators for such variables as energy prices, efficiency levels attained by key technologies, or

technology shares in energy supply, are widely employed in the presentations, although the scenarios are not backed by large-scale simulations. Since 1995 the Shell scenarios have considered a time horizon of about 50 years into the future; in contrast, earlier Shell scenarios explored only shorter time frames.

The methodology used at Shell in scenario preparation is a consultative process that largely follows the steps outlined in the section above, and seeks the direct involvement both of the decision makers and of a large multidisciplinary team of experts.

The 1995 Long Term Energy Scenarios were based on the assumption of normal market dynamics but a fast change in the energy system. In both worlds considered by the two scenarios (named *Dematerialisation* and *Sustained Growth*) fast technological change fostered by open markets is able to reduce GHG emissions. In the *Dematerialisation* scenario, energy efficiency improves at a rate equal to the maximum observed historically, and technological advances allow spectacular efficiency gains in areas like vehicles and transport. Renewable energy gains a foothold by expanding in niche markets at first and becoming entirely competitive later, while depletion in some fossil fuels would push up their prices. Nuclear development is hampered by high cost and public acceptance problems. In the *Sustained Growth* scenario, renewables are characterised by very rapid market penetration, matching the development of oil in the past century, and reaching maximum potential (close to 50% of world primary energy) by 2050.

The latest of Shell's scenarios were released in the fall of 2001. They identify three decisive factors in shaping long-term change: resources, technology and social priorities. The main questions explored by the new scenarios revolve around these factors:

- how long will oil and gas resources be able to meet rising demand and what will replace oil in transport;
- what will drive market growth and cost reduction of renewables;
- how will a hydrogen infrastructure develop;
- what will social and personal priorities be, and how will they affect energy choices.

All these can be summarised by an overarching question:

"What energy needs, choices and possibilities will shape a global energy system which halts the rise in human induced carbon dioxide emissions within the next 50 years – leading to a stabilising of atmospheric carbon

levels below 550 ppmv – without jeopardising economic development?" (Shell International, 2001).

The question, which has a certain normative flavour, seems all too appropriate for the scope of our investigation.

Before developing scenarios that provide possible answers to the above questions, Shell's analysts considered present trends that are likely to continue into the future. These include the continuing – but changing – link between growth in income and growth in energy demand, or between income growth and attention for the environment; the saturation of certain energy needs, and the fact that, due to improving technology, newly industrialising countries need less energy at the same income level reached in the past by industrial economies.

Another long-term trend, often decisive for the success of a new fuel or technology, is consumers' willingness to pay a premium for superior attributes of an energy carrier/product (convenience, cleanliness, efficiency). This appears to be especially true in industrial countries where consumers seek energy possessing such characteristics as availability on demand, density, safety, cleanliness, portability, ubiquity and unobtrusiveness. Cost and lead-time in energy infrastructure construction, as well as some physical limits to the expansion of fuel/technology market share, are further elements in the list of important but quite predetermined factors.

Similarly, population trends, income growth, market liberalization trends, and energy demand growth are powerful forces in shaping the socio-economic context for energy, without being fundamental in energy transitions. Demographic trends are fairly well understood and predictable: growth to 8.5 billion people by 2050; ageing population profiles, even in developing countries, and urbanisation of 80% of world population by the end of the period. Slower income growth (3.5% per year as a world average) than in the past century would still push growth in energy demand over the coming 50 years, to probably three times as much as now, but demand saturation would be in sight. Increasing investment in energy efficiency, even with present-day or anticipated technologies, could permit global energy demand growth by 2050 to be only twice as much as today.

Shell's analysis considers that three factors carry much of the uncertainty – and therefore potential for change in the energy system.

Energy resource scarcity, though a rare occurrence at a global level, is one factor that might trigger discontinuities in the system within the next 50 years. Although scarcity is excluded for coal over this time frame, costs

of extraction and use might affect its competitiveness. The peaking of oil production is approaching but if unconventional sources are included, scarcity is very unlikely before 2025 and that moment can be pushed another 15 years down the road by vehicle efficiency measures. New supply can still be brought in at costs of less than 20$/bbl for at least the coming decade and the cost of bio fuels should fall below that benchmark within the coming 20 years, constraining oil prices. Even more uncertain is the future availability of gas, for which scarcity could set in from as early as 2025 – to well after 2050. The real issue is timely development of gas transport infrastructure. Nuclear is likely to remain uncompetitive with respect to gas for another two decades, even with emission constraints, but this might change later. Finally, renewable energy resources are potentially plentiful but, especially for wind and solar, development is constrained by lack of appropriate energy storage technology, and cost competitiveness with respect to conventional energy is still not established.

Technology is another area that could bring potentially disruptive surprises. This is especially true in two areas: solar photovoltaics and hydrogen fuel cells. These two technologies, however, display fundamental weaknesses: the first needs significant cost reductions and the acquisition of new forms of storage; the second requires a new fuel transport infrastructure. The uncertainty is whether these two technologies posses sufficiently superior attributes to induce widespread adoption even at premium prices.

Finally, the third key uncertainty is represented by social and personal priorities, particularly attitudes towards energy security or self-sufficiency and attitudes towards the environment. These factors, together with timing, would play differently with respect to any given energy technology or resource and may significantly influence the outcome or the type of solution with respect to climate change.

Around these three axes, Shell analysts built two new scenarios to explore two different paths to a sustainable energy system. A sustainable outcome is consistent with Shell's professed environmental attitudes; it puts a normative character to scenarios that would otherwise be of the exploratory type. While different in focus, both scenarios ultimately converge on a "sustainable" future.

The two scenarios (called *Dynamics as Usual* and *The Spirit of the Coming Age*), described in Appendix I, suggest that by the middle of this century an affordable and sustainable energy system could indeed be emerging. They also show some common traits that should be carefully taken into account in outlining any sensible energy strategy:

- a role of natural gas as a bridge fuel over the next two decades and the importance of security in its supply;
- a strong volatility in oil markets;
- a shift towards distributed or decentralised heat and power supply;
- the potential for renewables and the importance of energy storage technologies (both for power and for hydrogen);
- the difficulty of identifying winning technologies in periods of high innovation and experimentation.

Stockholm Environment Institute - Global Scenario Group

In 1995 the Global Scenario Group at the Stockholm Environment Institute in Boston launched a project, which was to run over several years, on scenarios to explore the problem of transition to sustainability in a global and long-term perspective.

The team of experts and scientists involved in this work recognised the manifold dimensions of globalisation (geo-political, cultural, technologic, economic, biologic, climatic) and the fact that *"the world system is at an uncertain branch point from which a wide range of possible futures could unfold in the 21st century"* (Gallopin et al., 1997). Their aim was to explore various scenarios of the future and consider their implications. Since the start of the project the GSG has developed six scenarios outlined in three major reports.

"The increasingly interdependent global system we observe today is a way station in this sweeping process of growth, transformation and expansion. But a new and ominous feature of the current phase of history is that human impacts on the environment have reached global scales. The contradiction between the growth imperative of the modern world system and the constraints of a finite planet will be resolved. The critical question is, how?" (Gallopin et al., 1997)

This first question the GSG tries to address opens the way to a series of explorative scenarios, describing the range of possible worlds. An additional qualification to this question follows immediately: how can the contradiction between continued growth and the constraints of a finite planet be resolved in a sustainable way? This second question is explored by at least one normative scenario after a discussion and clarification of the sustainability notion.

The scenario building process followed by the GSG starts with a characterisation of the current state and of the driving forces, providing a representation of the conditions of the socio-ecological system and the major factors propelling the system forward. Then the scenario description requires the identification of critical uncertainties, the resolution of which will alter the course of events.

The GSG recognises the role of deliberate human actions and choices (influenced by cultural preferences, social visions and psycho-social factors not entirely understood) in shaping the future. As a complement to driving forces, the concept of *"attractive and repulsive forces"* is introduced (Gallopin et al., 1997): these are defined as "forces that can substantially redirect beliefs, behaviour, policies and institutions towards some futures and away from others" (Raskin et al. 1996). As an example of such attractive and repulsive forces the authors include subjective visions of the future, which, operating through human awareness, choice and action become objective forces shaping the evolution of the system.

Finally, these forces shaping the future must include so called *"sideswipes"*: surprises or disasters, such as breakthrough technologies, wars, extreme natural disasters, pandemics or the breakdown of the climate systems.

Another important concept that the GSG considers critical in constructing scenarios is the distinction between slow and fast dynamics operating within the socio-ecological system. The former are typical of high-level structures (governance systems, economic modes of production, cultural preferences, and most environmental processes), while the latter characterise lower subsystem (*e.g.* responses of individual consumers to price signals). The tension between the slow process of high-level systems and the rapid changes of the subsystems may shape some of the critical uncertainties of the whole. In fact complex systems may become more vulnerable and brittle to the influence of fast change in the subsystems. One such case is the growing persuasiveness and speed of global communications, which accelerate high level processes and generate more potential surprises (Gallopin et al., 1997).

The GSG associates the unsustainability of the current global trajectory with three critical trends, which include: environmental degradation and resource depletion; increasing income disparity; poverty and marginalisation (Raskin et al., 1998).

The drivers that shape the present situation are separated into two categories: "proximate" drivers and "ultimate" drivers.

- Ultimate drivers include: values, desires and aspirations; structure of power; knowledge and understanding; human needs; long-term ecological processes (Raskin et al., 1998).
- Among proximate drivers the GSG includes: population size and growth; economic volume and patterns; technological choice; governance; environmental quality (Raskin et al., 1998).

Ultimate drivers are the factors chosen to give the basic characterisation to the GSG scenarios, while the proximate drivers are the ones more easily translated in illustrative parameters.

As mentioned, the GSG develops six scenarios, categorised within a two-tiered hierarchy of classes, based on fundamentally different social visions, and variants, reflecting different possible outcome within each class. The scenarios are mostly presented as narratives with the aid of a few indicators; however they are built on an impressive basis of hard data and the scenarios themselves have been quantified using the PoleStar system (see Kemp-Benedict et al. 2002).

The three classes are called *Conventional Worlds, Barbarisation*, and *Great Transitions*. They are characterised by, respectively, continuity with current pattern, fundamental but undesirable social change, and favourable social transformation.

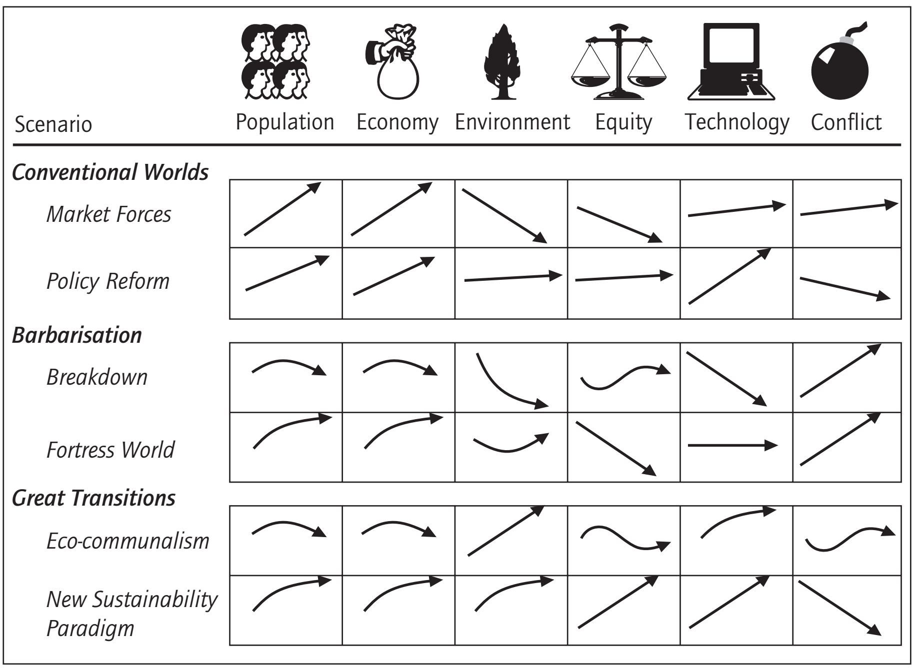
For each class two variants are defined. Within *Conventional Worlds* a *Reference* scenario is developed around mid-range population and economic development projections and using typical technological-change assumptions, while the *Policy Reform* scenario is characterised by strong, proactive governance in pursuit of sustainability, greater social equity and environmental protection. Both scenarios in this class show a continuity of institutions and values, rapid growth of the world economy and the convergence of world regions towards the patterns set by industrial countries.

The *Barbarisation* scenarios outline a future of deterioration of the social, economic and moral structures of civilisation as markets and policy reforms become incapable of coping with emerging problems. Its *Breakdown* variant features uncontrollable conflict, institutional disintegration and economic collapse. The *Fortress world* scenario is characterised by an authoritarian response to the threat of breakdown, by which the rich elite tries to protect itself and its privileges by controlling and repressing an impoverished majority.

The *Great Transition* scenarios examine visionary solutions to the problem of sustainability, through fundamental changes in values and in socio-economic arrangements. In these scenarios population levels are stabilised at moderate levels and materials flows through the economy are dramatically lowered as a result of lower consumerism and use of environmentally friendly technologies. The *Eco-communalism* scenario represents a regionalist and localistic vision characterised by small-is-beautiful and autarkic concepts. The *New Sustainability Paradigm* scenario shares some of these goals but tries to build a more humane and equitable global civilisation rather than retreat into localism.

Figure 1.1 offers a quick reference, for the six scenarios, of the behaviour over time of six descriptive variables: population growth, economic scale, environmental quality, socio-economic equity, technological change and degree of social and geopolitical conflict.

Figure 1.1 Summary Table of GSG Scenarios and Trends in Some Key Variables



Source: Gallopin et al (1997)

World Business Council for Sustainable Development

In 1997 the World Business Council for Sustainable Development (WBCSD) launched on behalf of its partner companies an effort to formulate a set of global scenarios to explore possible responses to the challenge of sustainable development. In particular the underlying question was how businesses can respond to these challenges (WBCSD, 1997). No less than 34 multinational corporations participated in this project, which was led by a core team of experts from WBCSD, Shell International and the Global Business Network. The resulting global scenarios were intended to provide a framework for focused industry or corporate scenarios.

The process of scenario building was conducted following the approach outlined on page 21. At first, trends that emerged in the last 50 years were described and the major global threats to the environment and its viability were identified. These include: loss of crop- and grazing land; depletion of tropical forests; extinction of biological species; rapid population growth; shortage of freshwater resources; over-fishing, habitat destruction and pollution of the marine environment; threats to human health; climate change related to GHG concentrations in the atmosphere; acid rain and air pollution; pressure on energy resources. Among the solutions to these problems is development of technology. However, diffusion of new technology is a time- consuming process and our ability to absorb it depends less on its availability than on our appreciation of its importance, which slows our capability of taking action against environmental threats. Another key element in the concept of sustainable development is the idea of economic prosperity for present and future generations and of social equity for all, without which misery, war and social conflict can result on a planetary scale.

From this analysis two key elements of uncertainty emerge, around which the scenarios are developed:

- what are the critical environmental thresholds and how resilient is the global ecosystem?
- what human social systems can best respond to the challenge of sustainable development?

Three key driving forces are identified which can be considered as "predetermined" elements that will certainly persist into the future and shape all scenarios:

- social and technological innovations, new economic and social actors;
- population increase;

- increasing interdependence and interconnectedness, thanks to new communication technologies that increase the speed of knowledge transfer, but unfortunately do not yet raise the speed of problem solution, due to the growing complexity of governance.

Around these questions and factors three scenarios are developed: the *FROG (first raise our growth)* scenario; the *GEOpolity* scenario; and the *Jazz* scenario. They are illustrated in Appendix I.

These scenarios explore the two questions above but develop around different possible human responses to the challenge of sustainable development, in other words, around the values and beliefs (or myths) held by the individuals. Elements of plausibility are abundant: most of their underlying trends can be found to be operating at present. Yet it is virtually certain that none of them will be entirely true: real life is going to be a mix of them, but understanding how some of those trends might actually develop and work is certainly a good way to prepare for them.

Intergovernmental Panel on Climate Change Scenarios

The Intergovernmental Panel for Climate Changes has periodically prepared long-term global scenarios focusing on emissions of greenhouse gases that can be used for the purpose of assessing climate change, its impacts, as well as adaptation and mitigation options. The IPCC has produced such scenarios in 1990, 1992, 1994 (a re-evaluation of 1992 scenarios), and then a Special Report on Emissions Scenarios in 2000. The 1992 scenarios (known as the IS92) were the first to provide estimates for the full set of greenhouse gases; these estimates were in turn used to drive global circulation models to develop climate change scenarios.

In 1996 the IPCC decided to develop a new set of scenarios, taking into account input and perspectives from a wide, interdisciplinary research community in an innovative "open process", which allowed consideration of different social, economic and technological factors and their impacts on emission trends. The scenarios, exploring a temporal horizon that extends to 2100, do not include future policies explicitly to mitigate climate change and specifically do not assume implementation of the UNFCCC or of the emissions targets of the Kyoto Protocol.

The process involved:

- an extensive review of the existing scenario literature;

- the analysis of the main scenario characteristics, their different driving forces and their relationships;
- the formulation of four main storylines as narrative description of as many alternative futures;
- the quantification of the storylines through the use of a wide array of models and modelling approaches;
- the review of the resulting emissions scenarios and of their assumptions through an open consultation process;
- repeated revisions, following this review process, of the scenarios and of the Special Report before its release in 2000.

As a result of the early stages of the analysis, the team of IPCC experts identified as the main drivers of future greenhouse gas trajectories factors like demographic trends, social and economic development and the rate and direction of technological change. Energy demand levels and land use patterns are directly influenced by these factors.

Based on the results of the literature review and on new data, population projections were revised downwards with respect to the 1992 scenarios. Furthermore all scenarios are characterised by growing per-capita incomes, as a result of gross world product increases of 10- to 26-fold depending on the case; income differences across world regions are assumed to narrow down in many of the scenarios described. Technology is considered a key driver at the same level as population change and economic growth: in fact the same assumptions on income and population dynamics can lead to greatly divergent paths in terms of energy demand and environmental impacts depending on the technology or energy resource assumptions used. These different assumptions in the SRES scenarios span a wide range of energy structures and systems. Finally land use patterns and related assumptions (particularly those related to trends in global forest areas) are of significant importance in these scenarios: although in most of cases forest areas are assumed to decrease for the first decades, ultimately a reversal of this trend is projected (IPCC-WGIII, 2000).

Four storylines were elaborated. Besides excluding consideration of climate change policies, these scenarios also excluded outlying (i.e. extreme with respect to the literature) "surprise" or "disaster" scenarios. Each of the storylines represents a combination of different demographic, social, economic, technological and environmental developments, and

describes consistently the relationships among those drivers without expressing judgements or preferences for one scenario versus the others. The storylines are described in Appendix I. Within those four main storylines a wider set (or family) of quantified scenarios is developed using a broader range of values for the main driving forces identified as well as different modelling approaches: most of the models represent integrated assessment frameworks. The resulting set of 40 quantified scenarios covers a wide range of uncertainties on future GHG emissions deriving from:

- Uncertainties in the parameters expressing the driving forces (demographic, social, economic and technological ones). It is interesting to note that 13 of these scenarios are devoted to the exploration of differences stemming from different energy technology assumptions.
- Differences in models' characteristics and structure.

It is important to note that no probability of occurrence is assigned a priori to these scenarios.

The four storylines, from which originate four scenario families, assume distinctly different directions for future developments and end up diverging in increasingly irreversible ways: together they encompass a significant portion of the uncertainties implicit in the main driving forces identified. The four storylines or scenario families are called respectively A1, A2, B1 and B2 (IPCC-WGIII, 2000). Within the A1 family three scenario groups are identified, characterising three different developments of energy technologies: A1FI is fossil fuel intensive and includes six scenarios simulated by different models, A1T describes a predominantly non-fossil fuel case (simulated with three models), and A1B is a balanced case (eight simulations with different models). The families A2, B1 and B2 have six, nine and, respectively eight scenarios.

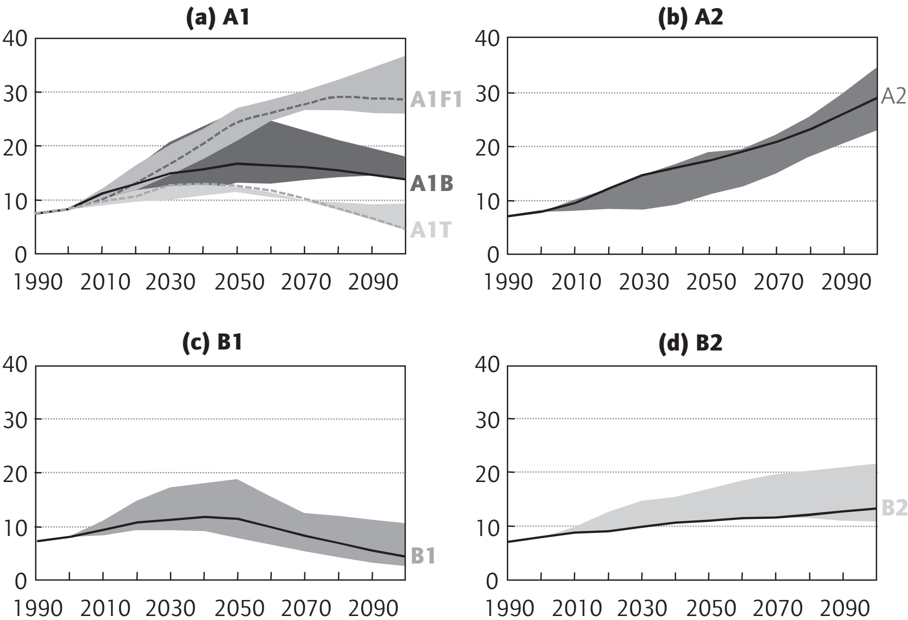
Within each scenario family two different types of scenarios were developed: scenarios with harmonised assumptions about economic growth, population trends and final energy use (there are 26 of them) and scenarios with alternative qualifications of the storyline (14 scenarios) to explore additional uncertainties. Marker scenarios are, for each storyline, the scenarios that best illustrate that storyline.

Based on the above assumptions and storylines, the SRES scenarios quantified through the use of a set of six models, span almost the entire range of carbon dioxide, other GHG and sulphur emissions found in the current scenario literature. Furthermore the six scenario groups cover a rather wide and often overlapping range of emissions, which fan out the

farther we go into the projected future. It is important to note that similar GHG emissions trajectories can be produced by very different socio-economic developments and, conversely, similar developments of the driving forces considered may result in different future emissions: it is the uncertainty in the future development of key factors that may cause large swings in future emissions, and which is responsible for the overlapping of projected emission ranges (IPCC-WGIII, 2000).

The range of cumulative emissions from all sources as quantified by the SRES scenarios through the year 2100 goes from 770 Giga-tonnes of carbon to 2540 GtC. The lower bound is approximately the same as the one estimated for the IS92 scenarios, while the upper bound is higher than the maximum range reached by the IS92 scenario (estimated at 2140 GtC). Cumulative emissions are a key element in governing any stabilisation of concentration, more so than the pattern of change of emissions from now until the time of stabilisation (IPCC-WGIII, 2000).

Figure 1.2 Global CO_2 Emissions for Six IPCC/SRES Scenario Groups-GtC



Source: IPCC-WGIII, 2000.

As shown by figure 1.2, some of the SRES scenarios show trend reversals, turning points as well as crossovers (i.e. cases in which initially emissions are higher in one scenario but later emissions are higher in another one). In most

cases of trend reversals, the increasing emissions trend due to income growth, is more than compensated for by productivity improvements combined with slower population growth (or even decline) (IPCC-WGIII, 2000).

Millennium Project

The Millennium Project of the American Council for the United Nations University is "a global participatory futures research think-tank of futurists, scholars, business planners, and policy makers who work for international organizations, governments, corporations, NGOs and universities". The project is carried out in partnership with the Smithsonian Institution, and The Futures Group International. It collects, assesses and manages judgements and analysis about the future and its global challenges from its network of several hundred participants: this information is used to produce annual "State of the Future" reports.

As a part of a project started in 1996 a series of global exploratory scenarios looking out to 2050 were developed and work was started to build normative scenarios as well. In this section we will outline the methodology and results followed in the construction of both types of scenario, as well as the approach followed to quantify the scenarios through the use of global models (ACUNU, 1998). The scenarios themselves are described in Appendix I.

The process of developing the scenarios, after a thorough literature survey, started with a questionnaire sent via e-mail to a certain number of correspondents. The questionnaire presented a list of 18 fundamental drivers or dimensions that could be used to span the scenarios, and asked participants to indicate the four most important. The list included such elements as communications technology (from vibrant to stagnant), degree of globalisation (from free trade to isolationism), pollution (from disastrous to being cured), population growth (from high to low), and so on. (ACUNU, 1998). Among the 35 responses to the questionnaire, the four highest-ranking drivers or dimensions were:

- degree of globalisation (from free trade to isolationism);
- communications technology (from vibrant to stagnant);
- threats to global security and or quality of life (high to low); and
- government participation in society (high involvement to little, or laissez faire).

Permutations of the extremes of these axes were used to form 16 possible scenarios. However, not all 16 scenarios were developed: only four were

considered worthy as the most interesting for further developments as exploratory scenarios, while two more where selected for development into possible normative scenarios (ACUNU, 1998).

A characteristic matrix was constructed to provide the essential outline of the four explorative scenarios' content. The purpose was to guide the team in preparing the initial narrative drafts. The matrix listed important elements in such domains as: demographics and human resources; environment and biodiversity; technology; governance and conflict; international economics and wealth; and integration. Then from previous work a checklist of issues (e.g. widening income inequality, increasing scarcity of fresh water, and so on) was drawn up and the most important of them (based on collective judgement by the team) elaborated in each scenario. This was done by trying to imagine what would be the consequences of those developments or issues in each of the worlds described. The same was done with a list of promising developments (e.g. diffusion of biotechnologies or new vaccines, acceleration of trends towards democracy) (ACUNU, 1998).

The next step was quantification through the use of models. At the beginning of the project, an informal enquiry was conducted among selected global modellers, about models and their potential uses in scenarios. Questions asked were: *What models would you consider for this application? Specific scenarios and generalised models don't match. Is it then necessary to build specialised models to quantify a specialised scenario? How can we effectively link specialised scenarios into more general global models? Do you know of any global models that are based on adaptive-agent modelling or on chaos/complexity principles?*

Responses to these questions showed that in the history of global model use in scenarios, early global models produced scenarios based on their projections – and there were no global models or studies in which the scenarios came first and produced the assumptions required for the model. When models are used this way, assumptions must be made about exogenous variables (such as population growth rate or productivity) (ACUNU, 1998). Choosing these exogenous variables always involves judgement on the part of the modeller, and values are often based on an implicit scenario:

Implicit scenario → Exogenous assumptions → Modelling → Scenario construction based on model runs.

Other respondents indicated that a high degree of quantification does not necessarily equate to accuracy, and that no matter what the model, simplicity was a desirable characteristic. Some recommended the use of modelling approaches that depend on judgements – heuristic modelling – rather than historical statistics for their relationships. A few recommended presenting outputs of futures studies in the form of dynamic, interactive computer programs adapted to the needs of decision-makers. Most stressed the danger that a policymaker, when presented with a scenario in quantified form, may confuse precision with accuracy, while what is in fact needed is to render uncertainty more explicit (ACUNU, 1998).

For these reasons the Millennium project decided to use models to help assure consistency, but having the scenario drive the model rather than vice-versa. In this perspective, the explicit scenarios illustrated earlier, were used to provide the backdrop for the choice of the values for the exogenous variables in the selected model. Therefore, when the model was run, its output was consistent with the scenario on which the exogenous variables were based and the model provided quantitative estimates of the value of variables that were incorporated in the scenario. Hence:

Lookout panel developments + Scenario axes → Scenario construction → Exogenous assumptions → Modelling → Scenario quantification (based on model runs)

The model International Futures (IF), made available by Barry Hughes of the University of Denver, was selected based on its user-friendliness. In order to run the model, a matrix was produced in which the columns consisted of exogenous parameters (or "*handles*") in the IF model, and the rows of specific scenario features. The team members entered judgements into the cells of this matrix, depicting the effect (in terms of increase or decrease) of the scenario features on the variables of the IF model. However, there were many anticipated effects that the model could not handle, either for lack of parameters or due to its structure (ACUNU, 1998).

This procedure was carried out for each of the scenarios to assign values to each of the scenario-dependent variables: in some cases the values were given elements of the scenarios, while in others they were judgmental and selected to be consistent with the spirit of the scenario. Finally, the explorative scenarios and the model outputs were sent to a selected group of experienced scenario writers and political experts for comments and revision. The resulting exploratory scenarios (called *Cybertopia*; *The Rich Get Richer*; *A Passive Mean World*; and *Trading Places*) are illustrated in Appendix I.

A comparison across these scenarios, carried out through scenario quantification, shows that by 2050 world population is highest in the *Passive Mean World* scenario and lowest in *Cybertopia*, world GDP is highest in *Cybertopia* although *Trading places* has highest growth between 2020 and 2040. CO_2 concentrations are highest in *Cybertopia* and lowest in *Mean worlds* and atmospheric temperature follows the same pattern. World literacy is highest in *Trading places* and lowest in *Mean world* (ACUNU, 1998).

Concerning the normative scenarios, the process followed for their construction required the identification of four primary norms from a list of 15 goals circulated among a panel of experts. The four most important were 1) environmental sustainability; 2) plenty (all people have basic necessities of life); 3) global ethics (identified and accepted); and 4) peace. These norms were meant to form the core of the normative scenario, while the body of the scenario was composed of the actions to address the stated global challenges. After a first draft of the scenario, a panel of long-term normative-oriented experts reviewed it and improved it (ACUNU, 1999).

The *Normative World* in 2050 is a world that has finally achieved an environmentally sustainable global economy, capable of providing nearly all people with basic necessities and a majority of them with a comfortable living. The resulting social stability produced relative peace giving leisure to people to look ahead for the second half of the 21st century. Three different specifications were developed for this scenario depending on what were thought to be the main forces capable of bringing about such a future. The three forces were: a) breakthroughs in science and technology; b) development of the human potential; and c) political and economic policies (ACUNU, 1999).

Country Scenarios

Canada: Energy Technology Futures

In June 1998 Natural Resources Canada (NRCan) started the project "Energy Technology Futures" with the aim of provoking and informing strategic thoughts among Canadian citizens and with government bodies about the range of possible futures in energy technologies and systems. The focus was on technologies that could fundamentally alter the relationship between economic growth and GHG emissions over the period from now to 2030-2050. A secondary aim of the project was to improve NRCan's long-term planning capabilities (Cliffe, 1999). The project was

completed in the spring of 2000, after a long series of workshops and meetings with experts from industry, government, business and universities, mostly in Canada but also in the U.S. and Europe. From this work the ETF team produced four plausible scenarios of what the Canadian energy technology system could look like 30 to 50 years into the future, in terms of global context and of how Canada would fit into that world. These have been extensively reviewed and refined afterwards.

The scenarios focus on energy sources, energy carriers and energy technologies rather than policy, regulation or behaviour. They discuss the energy system that could be used in Canada for the way people live, work and move goods and passengers. Furthermore each scenario provides estimates of energy demands, fuel mix and GHG emissions.

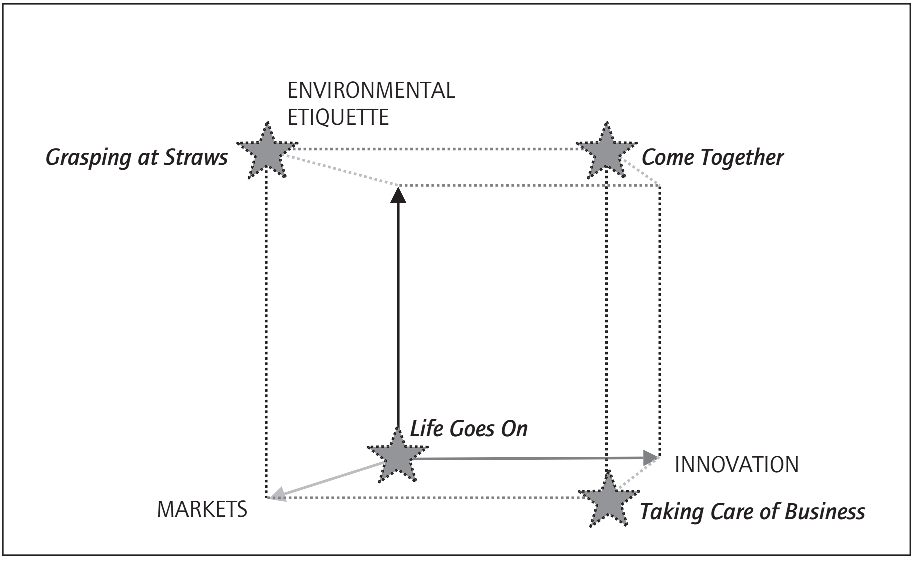
The scenarios are based on a few common assumptions, mainly concerning the stability and continuity in some trends and factors:

These are based on the recognition of existing trends in population dynamics, GDP growth and GHG emissions, and take into account the level of emissions that should be necessary to meet the Kyoto goals. Other trends specifically acting in the energy sector and expected to continue include the increasing electrification of the economy, driven by the growing penetration of information technologies; the integration of distributed energy system; consumer preferences oriented towards electric power reliability. (Cliffe, 1999).

At the beginning of the project a set of *technology perspectives or outlooks* was developed to provide a preliminary inventory of technologies currently at the conceptual or prototypical stage that could be further developed and deployed on a large scale in the scenario period. These included technologies for mobility, drives, process heat, space conditioning, illumination, biotechnologies, alternative and renewable energy; hydrogen; electricity production, electricity transmission and storage, integrated processes, biotechnologies and GHG capture, disposal and re-use.

The scenarios were developed around three key drivers, selected after accurate analysis: environmental etiquette i.e. how business and the public view environmental issues (grey to green); international markets and the degree of openness and globalisation of the world economy (open or closed); the rate of change of the innovation system within Canada (rapid or slow). These three variables defined the axes for the "planning space" in which the scenarios were built as illustrated by figure 1.3.

Figure 1.3 ETF Scenarios in their Planning Space



Source: Cliffe, 1999.

With the help of an ad-hoc modelling framework (based on NRCan InterFuel Substitution Demand Model) these scenarios have been quantified and translated into rather different levels of primary energy demand around 2050 and different fuel mixes. Primary energy demand would total around 16500 Petajoules in "Life goes on" (the closest value to a Business As Usual forecast), 13500 Pj in "Grasping at straws", 12000 Pj in "Taking care of business" and 10500 Pj in "Come together". Fuel mix would range between 82% fossil fuels in "Life goes on" to 53% fossil fuels in "Come together", the rest being supplied by nuclear, hydro and other renewables. Nuclear however plays a role only in "Taking care of business" and "Come together" worlds, under the pressure of a strong environmental etiquette, while gas is dominant in the two other scenarios. Correspondingly, total GHG emissions (including non-energy sources of emissions) would range from 1125 Mt in "Life goes on" to 325 Mt in "Come together". The transport and power generation sectors would remain the largest emitters even in the scenario "Come together".

These scenarios raised a number of issues and questions on the role of specific technologies such as nuclear (which could experience a strong comeback according to some scenarios, especially in conjunction with other enabling technologies), GHG capture and disposal, hydrogen, and renewables. The importance, across the entire spectrum of energy sources, of enabling technologies like semi-conductors, nanotechnologies,

biotechnologies and IT, large-scale power storage, and the sensitivity of infrastructure investment and security were particularly stressed by this project.

The Netherlands: Long-term Outlook for Energy Supply

The Dutch Ministry of Economic Affairs has recently been involved in building and using storyline scenarios in strategic decision-making within the Dutch government. The intention of the project "Long Term Outlook for Energy Supply" was to provoke discussion about the Netherlands energy supply around 2050 (Ministry of Economic Affairs, 2000). Its focus was on devising a strategy – or set of strategies – for investment decisions, sustainability and research and development, which result in minimum regrets. In particular, the goal of sustainability strongly contributes to the characterisation of the Dutch government's view of the future. The scenario approach, requiring the identification of underlying forces that shape the future and a deeper understanding of uncertainty, proved to be a particularly challenging one to convey to politicians.

The project set out to identify long-term trends affecting the Dutch energy system and the main drivers for the future, separating as much as possible certainties and uncertainties. First the main determinants of energy demand and supply were analysed (population, economic activity level or income, energy intensity of the system, consumer preference, energy resources available and their reserves, technologies available).

The analysis showed that at global level demand would increase following population and income increase: energy efficiency improvements will slow down growth in demand but not offset it. Sufficient energy supply is available to meet this growing demand, but a shortage of easily recoverable, cheap oil is likely to occur in the first half of the century, and alternatives will have to be found. These will be largely determined by public preferences. The energy market will be increasingly dominated by electricity. The matching of supply and demand will continue to take place subject to the preconditions of uninterrupted supply, economic affordability and ecological suitability but the relative weight of these three elements will vary depending on the world envisaged and by whether or not there will be global institutions to establish common preconditions (Ministry of Economic Affairs, 2000).

The preliminary analysis thus revealed that the most important factors of uncertainty to be taken into account are collective, socio-cultural values, in particular: Will people measure the achievements of the economic process

against short-term monetary gain or against long-term public interest such as the global environment? Will people recognise the problems together and leave the solution to global institutions or will they seek solutions on their own at the local level? These uncertainties turn out to be even more important than those linked to technologies or GDP growth rates (Ministry of Economic Affairs, 2000).

Consistent with this finding, the storyline scenarios developed for the Netherlands are built along socio-cultural "axes". In particular they are identified within the space defined by the institutional dimension ("global government" *vs.* "local structures") and by the dimension of values ("profits here-and-now" *vs.* "gains for the world"). In this "space" four alternative but internally consistent scenarios were defined, characterised as: (1) isolation, or *the fearsome man scenario*; (2) small scale ecology – or *the conscious father scenario*; (3) great solidarity – *or the global citizen scenario*; and (4) free trade – *or the consuming individual scenario*.

As future outcomes can be influenced by political will, policymakers need to define a set of criteria and priorities drawn from present society's values when planning for the future. The scenarios elaborated for the Netherlands are tested according to criteria of security of supply (including issues related to geopolitical stability), economic efficiency (in terms of cost allocation and equity), and sustainability (in terms of low emissions and efficient resource use). The "Great solidarity" scenario is the one that meets most criteria. Based on these criteria and on the commonalities identified across scenarios, the transition agenda can be defined (including infrastructures, technologies, etc.) according to a "least regret" strategy.

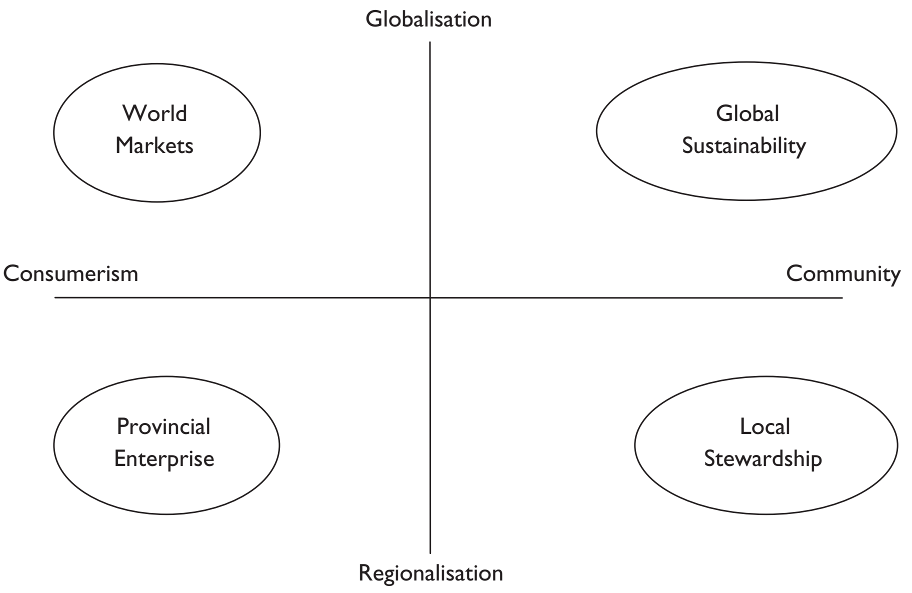
The United Kingdom Foresight Program – Energy Futures

The United Kingdom Foresight Programme, created under the Office of Science and Technology at the Department of Trade and Industry has developed between 1999 and 2001 several energy and environment scenarios looking out to the next 40 years. The primary objective of the project has been *"the identification and highlighting of key opportunities and challenges posed by future changes in the supply and demand of energy and natural resources and those posed by pressures on the environment"* (UKDTI, 2000). Furthermore the project intended to develop a robust view of the research and development activities that would help secure a strong international position for the UK in the future while meeting the other demands of society. The need for a longer-term vision was recognised in light of the challenges of sustainable development and

of the environment, and also to balance the almost total emphasis on short-term business issues in today's energy sector.

A scenario-based process was adopted as it better served the purpose of identifying common trends that are relevant across a wide range of potential future situations to provide a set of strategies that are robust against different outcomes. The preliminary analysis highlighted the importance of several factors in determining these scenarios. These include: economic growth; industrial structure; fiscal and regulatory policies; environmental awareness; local and global environmental policies; energy consumption; energy security; energy cost; preference for embedded or distributed power; and technological change. The scenarios are placed in a two-dimensional space determined by two main axes of governance (from globalisation to regionalisation) and social values (from community values to consumerism). As shown in Figure 1.4, four different future scenarios are elaborated.

Figure 1.4 Foresight Scenarios for the United Kingdom



Source: Performance and Innovation Unit Energy Review: *Energy Scenarios to 2020*. September 2001.

From this scenario exercise some robust messages are drawn concerning energy R&D areas that appear to be of crucial importance in a majority of the scenarios analysed. These areas include:

- network issues for distributed generation systems;
- development of more sustainable power generation technologies, whether conventional, renewable or nuclear;
- increased efficiency in both generating technologies (including CHP) and end-use technologies;
- transportation technologies such as fuel cells and associated infrastructure;
- biomass and waste utilisation;
- large scale energy storage;
- carbon dioxide sequestration;
- improved fossil fuel extraction (conventional and unconventional);
- regulatory mechanisms to facilitate emission trading, investment in energy efficiency;
- social science investigation of behavioural issues.

Other recommended areas of investigation, albeit with a reduced R&D component, were: the creation of future infrastructure or adaptation of existing ones; migration of electricity infrastructure (from centralised to disperse); transport fuel migration (replacement of today's oil based fuels with new fuels); reconsideration of nuclear power issues in light of the need to decarbonise the energy base (UKDTI, 2001).

A Critique of Scenarios

Table 1.1 offers a synoptic view of the scenarios according to their main characteristics: *time-scale* explored, *purpose, type* of scenario (narrative or quantitative), *model* used to quantify the scenario, *main drivers* identified.

The sample analysed here includes scenarios that look either at the 2050 or the 2100 horizon. They are mostly **narrative scenarios**, although a large number of them have been at least minimally quantified. Among the **quantified scenarios**, the sample ranges from the IPCC scenarios, each of which has been quantified with three to six different models and in many cases considering variations of the characterising parameters around some central value, to scenarios quantified with the help of spreadsheet calculations or simply of indicators.

As to the *purpose*, the majority of scenarios described are **explorative**; a significant number of them have been developed for strategic analysis and hence are used to test what strategies would be more robust or more resilient, with respect to a stated objective, in different worlds. This is clearly the case for the country scenarios examined (Netherlands, Canada and the United Kingdom), but also holds true for the WBCSD scenarios which indicate what business attitudes and style would fit best the various worlds analysed. A few scenarios have a **more or less clear normative content**. Sometimes these respond to questions of the type: what possible worlds could bring about a sustainable future as defined by stabilisation of GHG concentrations in the atmosphere below 550 ppm, or other indicators (like the Shell 2001 scenarios or the *Great Transition* scenarios of SEI-GSG). The most clearly **normative** scenario is the SEI-GSG *Policy Reform* scenario, which sets precise sustainability goals (in terms of income distribution and environmental pressure target indicators) and the Millennium Project *Normative World* scenario. As the scenario takes place in a *Conventional World* (not substantially different in values and social organisation from the one we know), attainment of the goals can only be pursued by bending the current growth trajectory through a rich array of policy instruments and measures. The Millennium Project's *Normative World* scenario (and its variations) starts from a very clear definition of the norms but does not quantify objectives and does not indicate specific policies for actions to bring about that world: in this regard is more similar to the SEI-GSG Great Transitions scenarios.

One aspect that deserves more detailed attention is the *list of drivers* that are commonly found in these scenarios. An interesting distinction made by some of the scenario developers is that between **ultimate drivers** and **proximate drivers** (SEI-GSG), or between **drivers** and **predetermined elements** (WBCSD) or else between **main uncertainties** and **other drivers** (Dutch Ministry of Economic Affairs).

These distinctions seem to hint at some ranking among drivers, between those that capture the most uncertainty or which have deeper and stronger implications, and those that are in a way derived by the former. It is the **ultimate drivers**, or the main uncertainties that represent the axes along which the scenarios are developed.

Interestingly enough, in most cases these drivers refer to the human element: they represent "human responses", "socio-cultural values and priorities", "desires and aspirations", "environmental etiquette", or the "social structure" and "organisation of power". Another category concerns

"resources" and "long-term ecological processes" most of which lie entirely outside the human domain and control. A third element is technology, an element typically within the human domain but still highly dependent on unpredictable and often random factors.

Among the **proximate** or **derived drivers** we find elements like population dynamics, level of economic activity (GDP), technological choice, which are found more often as exogenous variables in modelled scenarios.

During a seminar on long-term scenarios organised in October 2001 by the IEA, participants in small group discussions engaged in an attempt to define a list and a ranking of main drivers. These were then grouped into clusters. Drivers discussed on that occasion are virtually the same as the ones emerging from this literature review. Participants in the 2001 seminar ranked technology and technology-related factors highest, followed by a broad cluster that included values, lifestyle, and behavioural elements particularly of certain actors. Third came income and income distribution, followed by population. Security issues, investments and shocks were at the bottom, apparently not being considered particularly critical in shaping our long-term energy and environmental future. Energy resources and environmental constraints were in mid-to-low section of the list; however, attitudes of the general public towards the environment, as a part of the cluster Values, lifestyles and other behavioural elements, rank very high. This could indicate that the perceived importance of the environmental issue might be more important in shaping the future than the environmental constraints themselves.

As for the types of worlds described, it is interesting to note that a few cases recur rather often. Among **negative and undesirable** scenarios we find the extreme case of the two *Barbarisation* scenarios of SEI-GSG, the A2 family of IPCC scenarios, and the Dutch *Isolation* scenario. These scenarios are characterised by egoistic values, lack of concern for the environment, isolation and closure of markets: they usually end up in collapse of both the environment and of human society. In a similar vein, although characterised by negative environmental consequences and not social collapse, are the A1FI of the IPCC, the evolution of the *FROG* scenario of WBCSD the Canadian *Life goes* on scenario, and the *Provincial Enterprise* scenario of the UK.

Among the **environmentally benign** scenarios we find cases like *Eco-communalism* of the SEI-GSG, the B2 family of the IPCC, *Grasping at Straws* of Canada, *Ecology on a Small Scale* of the Netherlands and *Local Stewardship* of the UK. All those scenarios are based on strong concern for

the environment but with a local focus and/or slow technological innovation. But we also find scenarios like the A1T and B1 families of the IPCC, *Jazz* of WBCSD, the two Shell scenarios, the *New Sustainability Paradigm* of SEI-GSG, the *Cybertopia* world of the Millennium Project, the Dutch *Great Solidarity* scenario and the Canadian *Come Together* scenario, which are characterised by strong environmental values coupled with open markets and rapid technological change. As a result of this favourable combination of factors, the environment is often better protected than in the less market- oriented and less technologically innovative scenarios. Some of these scenarios are very optimistic about the natural capability of free markets to achieve all these goals without much regulatory intervention. Others like *GEOpolity* of WBCSD and *Policy Reform*, on the other hand, are scenarios driven by policy intervention carried out for the public and environmental good by national and supranational government entities and are characterised by moderate growth.

The recurrence of some of these images of the future is intriguing. It is not clear how much of this is due to the fact that certain development paths are clearly visible from our specific point of observation in time or whether there is some sort of imitation effect among scenario builders.

It is also interesting to note that most of the pessimistic or catastrophic scenarios are often less fully developed than the more optimistic ones. This, however, does not reduce the relevance of this type of scenario. There are at least two ways pessimistic storylines can be used, aside from the fact that forcing us to contemplate catastrophic outcomes may already be a healthy exercise. First, they help us spot early signs of those trends that may lead down undesirable paths so that we can start early to address the problems. Secondly, they help us prepare contingency plans in the event that negative situations do materialise. Consider global climate change. Most scientists believe it is already taking place, although we have a hard time pinpointing specific weather events and ascribing them to human-induced climate change. These phenomena become visible over long periods, but by the time there is certainty of their occurrence it may be too late for preventative action. In such a case we would be left scrambling to put in place crisis management and damage control measures. Some countries are already making plans in that direction, but some of the most vulnerable ones are too poor even to start making a map of their risks. To our knowledge, there is very little of that sort of forward thinking, even by the largest financial institutions.

One of the most interesting features displayed by some among these scenarios is the capability of sketching paths over periods of 50 years, in which some of the initial conditions are entirely reversed along the way (e.g. open markets and cut-throat competition leading a few decades later to trade wars and protectionism; reaction to extreme regulation; unbridled economic growth leading to environmental disaster and then to economic collapse). Over long-term horizons it is unlikely for the same trend to continue unabated.

A limitation found in most global scenarios, but not in country scenarios, is lack of explicit discussion of the technologies that might ferry us to sustainable futures (which technologies do we need and how do we develop them; where should we concentrate our research efforts and budgets?). Thus, it is the national scenario exercises carried out by Natural Resources Canada, by the Dutch Ministry of Economic Affairs and by the UK Department of Trade and Industry that result in lists of priority technologies that need to be developed. The usefulness of forward thinking of this type cannot be overstressed. In recent years, the processes of energy market liberalisation have led many energy companies to concentrate more on short-term R&D. At the same time governments have tended to get more involved in policies to widen the market for energy technologies that are more efficient but a bit more expensive or with which consumers are less familiar. While this is in line with the technology policy recommendations of the expert community, it is hardly likely to suddenly generate the "miracle technologies" that would solve our sustainability equations. In order to have a general sense of what might be appropriate types of investment in new technology, governments and large enterprises do not need to pick winners, but would greatly benefit from some technological road mapping. Such mapping might be more effective if facilitated through a process that helped establish where we want to be in 40-50 years or what type of situations we would like to avoid.

Another incompletely sketched aspect of the scenarios examined is that of bottlenecks in fossil fuel supplies that might well materialise in the coming decades. Some of the "conflict" or "breakdown" scenarios (like the WBCSD's *FROG* scenario or the SEI-GSG's *Barbarisation* scenario) contemplate worlds where oil or gas supplies become increasingly insecure due to closing markets and regional conflicts. These scenarios tend to favour coal as a refuge from energy supply shocks, with predictable environmental consequences. Most scenarios agree that there is no immediate threat of shortage of oil and gas reserves (although the situation may change for oil in about twenty years). Past experience shows

that supply shocks are usually short-lived and the system adjusts to them in a matter of a few years. Yet it is clear that the increasing dependence of developed and developing countries alike on oil reserves that are geographically concentrated in relatively unstable areas of the world presents risks. Scenarios of long-term instability in these areas would need to be investigated, and other situations of vulnerability of energy supplies better assessed. Potential security problems exist for oil- and gas-shipping lanes, oil and gas pipelines, and nuclear plants with respect, for example, to terrorist attacks. Other concerns can be associated with long lead times for infrastructure construction and related financial risk, or to nuclear proliferation issues.

Finally, it might be noted that those scenarios that actually envisage (either in a normative light or in an explorative context) a sustainable world or simply one where GHG emission concentration is stabilised at a "safe" level require either technological breakthroughs or truly gigantic efforts from society in terms of strong political will and/or epochal changes in consumer preference. In exploratory scenarios this type of factor can be assumed among the drivers while it is in normative scenarios that they can be fully appreciated. The role of these factors needs to be made more explicit, and the scale of efforts required for positive change needs to be better assessed.

Table 1.1 Summary Table of Scenarios Examined and their Main Characteristics

Developer	Scenario name	Type	Model used	Drivers	Purpose
Global scenarios					
Time horizon: 2000-2100					
IPCC / SRES 1996-2001	A1FI family	Both narrative and quantified	Each scenario was simulated with 3-6 models: AIM, ASF, IMAGE, MARIA, MESSAGE MINICAM	Population dynamics; Economic growth; Environmental quality; Equity, Technology; Globalisation trends	Explorative
	A1B family	Both narrative and quantified			Explorative
	A1T family	Both narrative and quantified			Explorative
	A2 family	Both narrative and quantified			Explorative
	B1 family	Both narrative and quantified			Explorative
	B2 family	Both narrative and quantified			Explorative
Time horizon: 2000-2050					
Shell International (2001)	Dynamics as usual	Mostly narrative		Resources; Technology; Social priorities	Explorative with some normative flavour
	Spirit of the coming age	Mostly narrative		Resources; Technology; Social priorities	Explorative with some normative flavour
SEI-GSG 1995-2002	Conventional worlds – Reference	Both narrative and quantified	PoleStar	Ultimate drivers: Values; Desires & aspirations; Structure of power; Knowledge & understanding; Human needs; Long-term ecological processes. Proximate drivers: Population size and growth; Economic volume & patterns; Technological choice; Governance; Environmental quality	Explorative
	Conventional worlds – Policy reform	Both narrative and quantified	PoleStar		Normative
	Barbarisation – Breakdown	Both narrative and quantified	PoleStar		Explorative
	Barbarisation – Fortress world	Both narrative and quantified	PoleStar		Explorative
	Great transition Eco-communalism	Both narrative and quantified	PoleStar		Explorative
	Great transition New sustainability	Both narrative and quantified	PoleStar		Explorative with some normative flavour

Table 1.1 Summary Table of Scenarios Examined and their Main Characteristics (*continued*)

Developer	Scenario name	Type	Model used	Drivers	Purpose
WBCSD (1997-99)	FROG	Mostly narrative		Human response to challenge of sustainable development; values and beliefs. Predeterminate elements: social and technological innovation; population increase; interconnectedness	Explorative
	GEOpolity	Mostly narrative			Explorative
	Jazz	Mostly narrative			Explorative
AC-UNU (1996-99) Millennium Project	Cybertopia	Both narrative and quantified	International futures	Main drivers, "axes" or "dimensions": Degree of globalisation; Communications technology; Threats to global security and quality of life; Government participation in society.	Explorative
	The rich get richer	Both narrative and quantified	Internatio-nal futures		Explorative
	A passive mean world	Both narrative and quantified	International futures		Explorative
	Trading places	Both narrative and quantified	International futures		Explorative
	Normative World	Narrative		Norms: Environmental sustainability; Plenty; Global ethics; Peace.	Normative
Country scenarios					
Time horizon: 2000-2050					
Dutch Ministry of Economic Affairs	Free trade	Mostly narrative		Main uncertainties: socio-cultural values; institutions & social organisations. Other drivers: economic growth; technology; sustainability	Explorative/strategic
	Ecology on a small scale	Mostly narrative			Explorative/strategic
	Isolation	Mostly narrative			Explorative/strategic
	Great solidarity	Mostly narrative			Explorative/strategic

Table 1.1 Summary Table of Scenarios Examined and their Main Characteristics (*continued*)

Developer	Scenario name	Type	Model used	Drivers	Purpose
Natural resources Canada – ETF	Life goes on	Narrative, some quantification		Main drivers: Environmental etiquette; Degree of openness of international markets; Rate of technological change	Explorative/strategic
	Grasping at straws	Narrative with some quantification			Explorative/strategic
	Taking care of business	Narrative with some quantification			Explorative/strategic
	Come together	Narrative with some quantification			Explorative/strategic
UK Department of Trade and Industry- Foresight Program	World markets	Narrative with some quantification		Main drivers: governance (from globalisation to regionalisation); social values (from community to consumerist). Other relevant factors: economic growth and structure, fiscal and regulatory policy, environmental policy, technological change; energy consumption, costs and security.	Explorative. Used to define R&D strategies
	Global sustainability	Narrative with some quantification			Explorative. Used to define R&D strategies
	Local Stewardship	Narrative with some quantification			Explorative. Used to define R&D strategies
	Provincial enterprise	Narrative with some quantification			Explorative. Used to define R&D strategies

THREE EXPLORATORY SCENARIOS TO 2050

Background

Final considerations in the previous chapter suggest that existing scenarios, while shedding light on a number of critical energy questions, do not adequately address the policy issues that must be confronted. The scenarios are, for the most part, policy neutral (that is, they do not assume any specific policies directed at reducing environmental impacts or security concerns). Furthermore, most posit significant shifts from current trends – but no convincing "story" is provided to enable the user to understand how to induce such changes. Shifts are manifest as major reversals in public perceptions (i.e., consumers around the world suddenly become ecologically conscious, and seek environmentally benign behaviours even at relatively high personal cost), or as technology breakthroughs (where prices for new alternatives decline precipitously – and seemingly by chance). Although there is no shortage of long-term scenarios in the literature, a number of key uncertainties could usefully be further explored through new scenario work.

However, before we set off to develop new scenarios it is useful to clarify:

- the purpose of the work;
- the relevant questions that we want to address;
- the key uncertainties that deserve further exploration.

The scenario-building process is usually undertaken from a specific viewpoint – either by governments seeking to evaluate specific policy needs, or by academics or industry experts with personal perspectives. Hence, to qualify the answer to the above questions, it is important from the outset to explain that the point of observation adopted in this work is clearly an IEA perspective. However the IEA, as an organisation made of 26 member countries, does not have a unique perspective to serve as a starting point for its analysis, beyond the definition of its mission and the shared goals of its member countries. It is hence necessary to go back to these foundations in order to formulate both the underlying issues to be addressed and the uncertainties that need further attention. For the same reasons, exploring a family of scenarios rather than single alternatives appears more appropriate.

The purpose of this work is to explore possible energy futures for energy and the environment over the coming 50 years. Although the perspective adopted is that of an organisation of industrialised countries, the scope of the analysis must clearly be global.

The questions and key uncertainties that emerge from previous discussion are for the most part related to energy security, environmental damage and technological development:

- **Will acknowledged energy resources actually be made available where and at the time they are needed?** Geopolitical risks exist that may cause disruptions in world supply; sufficient investment to build necessary infrastructure cannot be taken for granted; mismanagement in energy system reform may cause local shortages of power or gas. These are questions that promise to be in our agenda for at least the coming twenty years, and have both near and longer-term priority for policy action;

- **Will continuation of economic growth and satisfaction of our energy needs cause irreversible damage to the environment and thus compromise the welfare and safety of present and future generations? And by way of what conditions can we avoid such an outcome?** The last of these questions summarises the challenge of sustainable development and is one of the most serious (and perhaps most overlooked) challenges we face. As with the energy security issue, the problems (and efforts to mitigate them) will need our attention starting immediately – and continuing for decades.

Hence, the aim of these scenarios is to stimulate discussion about environmental sustainability of our energy system, security of supply, and energy technology development.

Scenarios to address these issues can be developed according to two alternative perspectives:

- We could explore different (but plausible) directions of development in our energy/economic systems and the type of implications they produce for energy security, climate change and related issues. If in the process some serious threats (energy supply disruptions, environmental collapse scenarios, or others) emerge as a result, scenarios can help us prepare for these events, either to avoid them or to control the damage after the fact;

- Scenarios can be developed in which specific undesirable events never occur – and we can then work backwards to figure out what to do now to ensure such events never materialise. Constructing such scenarios requires analysing what technologies might be needed and what policies might appropriately be implemented to avoid future damage.

In case (a) we would be dealing with *exploratory* scenarios while in case (b) we would work more on *normative* scenarios and using a *back casting* approach. Although we need to keep in mind the current trends, the initial condition and the inertia of the system, focusing on a "business as usual" scenario is clearly insufficient if we want to explore our initial questions.

The development of exploratory scenarios will be the subject of this chapter, while the development of a normative scenario will be taken up in chapter 3.

Methodology

The procedure commonly used to build exploratory scenarios was outlined in chapter 1. For this specific exercise the same steps were followed. Initial impetus in the construction of these scenarios came from input provided by various experts in scenario work gathered at an international seminar on long term scenarios organised in the fall of 2001 by the IEA. On that occasion a first attempt was made to identify factors, trends and main drivers that could have a strong role in shaping the future concerning energy and environment aspects. The results of that seminar were integrated into a more systematic analysis, supported by questionnaires and structured brainstorming sessions carried out within the IEA, that forms the background to the scenarios themselves.

As a first step, the system under investigation and its boundaries were identified. This consists of the energy system (including all elements of the chain from energy production to energy services demand, its technologies and actors involved) and the energy system context, which comprises the economic and social environment, as well as at least some interfaces with the natural environment. Information, expert opinion and past data were gathered on the economy/energy/environment system, identifying within this system all relevant actors and agents.

Key factors that would affect the system were then identified, clarifying the links (and feedback) between them and various parts of the system.

This analysis was carried out in a qualitative fashion based on existing knowledge, but whenever possible, causal links were identified much in the same way as is done in a deterministic model.

Factors and trends that could be considered as "predetermined" or "unavoidable" were distinguished from those that are highly uncertain or depend on will. Predetermined elements/factors represent those elements that remain unchanged in all scenarios and are listed among the common features of the scenarios developed. Factors that are both uncertain (in terms of direction of their development) and have potentially high impact on the system were identified and ranked through a sort of "Delphi process" and put in a separate category of "main drivers". This way a list of seven main factors or drivers was isolated, which included (in descending order of importance):

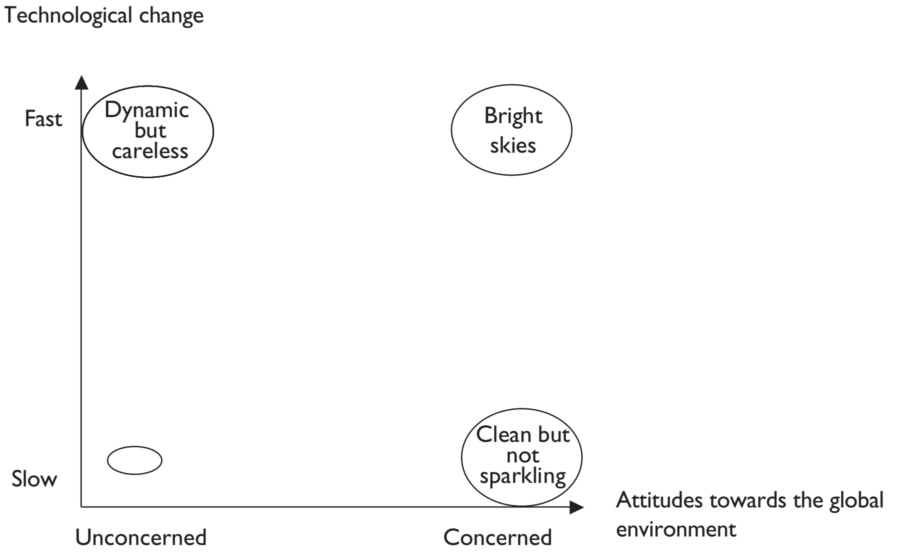
- technology or speed of technological change particularly in the energy sector (both on the supply side and the demand side);
- attitudes and preferences with respect to the global environment;
- economic growth;
- population growth;
- globalisation and degree of market openness;
- structure of power and Governance;
- global security issues.

For the purpose of this exercise, the two elements topping the list were chosen to represent the main axes along which our scenarios differ and are characterised in a sort of spatial representation. In the scenarios developed hereafter **the axis on technological change is seen to vary from fast to slow; the axis on attitudes and preferences with respect to the global environment varies from concerned to unconcerned.** The remaining elements are fully taken into account in the scenario narratives and remain as important forces, but their direction of change is often influenced by the two main drivers.

An infinite number of points can be placed on a two-dimensional space, each characterising a different scenario. By focusing on the extreme cases we have a chance to explore the full range of uncertainties deriving from those factors/drivers. It is therefore important to keep in mind that these scenarios are not built on the basis of considerations of likelihood in the probabilistic meaning of the word. The scenario methodology demands

that the combinations of factors around which scenarios are built be possible and allow the exploration of a meaningful case and that the story-lines be plausible. The specific combinations of drivers considered then produce the scenarios shown in Figure 2.1.

Figure 2.1 Three Exploratory Scenarios



Of the four scenarios illustrated in figure 1 only three were actually fleshed out in the form of consistent narratives or "stories", the one located close to the origin of the axes was considered to be close to the continuation of present trends.

The three scenarios developed were given names that characterise them immediately:

- **Clean but not sparkling:** describes a world of slow technological change, high concern for the global environment;
- **Dynamic and careless:** describes a world of fast technological change, low concern for the global environment;
- **Bright skies:** describes a future of fast technological change, high concern for the global environment.

These three scenarios are described in section below.

Three Exploratory Scenarios to 2050

Common Features of the Three Scenarios

As mentioned earlier, the three scenarios share some common features, given by those trends (already apparent in today's experience and broadly recognised) that are very likely to continue in the future. They are reported hereafter with some brief comments by areas of interest.

Population. Growth in world population will continue but is likely to slow down in the next 50 years. Growth will be concentrated in the developing countries. Other relevant trends include increasing urbanisation, especially in developing countries, leading to an increasing number of mega-cities in the South. By 2050, around 80% of world population is expected to be living in urban agglomerations. Population growth might be slightly slower in scenarios with strong concern for the global environment and fast technological change.

Income level and growth. Overall income growth is likely to be slower than in the past century. However economic development will continue especially in the South, with developing economies growing faster than developed ones. In the process some developing countries may be left behind. The scenarios developed allow for some variation (higher or lower growth) with respect to this trend, depending on the assumptions on the two main drivers.

The general trend is towards the progressive industrialisation of developing countries, although the type of industrialisation is not specified here. Development of the services sector is assumed to be part of the next stage, which in some cases might take place in an earlier phase of the economic development curve. Regional distribution of economic activities also varies. Tertiarisation in industrialised countries will continue, with an increasing role for the knowledge economy, although this phenomenon will not have the same intensity everywhere: some industrial countries may fall behind and end-up impoverished as a result.

Energy supply. The only common assumption across the three scenarios is that there are sufficient fossil energy resources to meet demand in the next 50 years; whether they will actually be extracted depends on the pace and direction of technological change and on the level of environmental concern. The matching of supply and demand will continue to take place at the global level, subject to the preconditions of uninterrupted supply,

economic affordability and ecological suitability. However, the relative weight of these three elements will vary depending on the world envisaged. In particular, location of the energy resources (both fossil and non-fossil) may be an important factor. Also, local imbalances on specific energy markets are possible.

Energy demand. Total primary energy demand will increase in aggregate terms in all scenarios. The link between growth in income and growth in energy demand will continue but its character changes depending on the scenario.

Thanks to improving technology, newly industrialising countries will be in a position to use less energy than did the industrial countries at similar income levels in the past. Whether this potential for lower energy intensity is fully tapped will depend on other scenario characteristics. Continuation of trends to improve energy intensity at least at the aggregate level is likely. At global level energy efficiency improvements will slow demand growth but not offset it.

The general trend will be towards convergence in energy end-use patterns and services between developed and developing countries although the convergence in energy consumption levels is not necessarily assumed. The range of energy services demanded in OECD countries (space conditioning, mobility, motor drives) will not be greatly altered over the scenario horizon; changes will be more rapid in developing countries.

The energy market will be increasingly dominated by electricity. Electrification of the economy in OECD countries will increase further. Consumer preferences are oriented towards electric power reliability in OECD countries. Also, consumers seek energy possessing such characteristics as availability on demand, density, safety, cleanliness, portability, ubiquity and unobtrusiveness.

In developing countries, progressive electrification of the economy will take place. This trend, along with the effort of bringing electricity to the millions of people without access to it, will be a major challenge in terms of infrastructure development and financing as well as policy. However, urbanisation trends are likely to simplify the task.

Concern for the environment. As a general trend, increased affluence will generate increasing environmental problems (e.g. waste disposal). Capacity and interest in addressing these problems will also increase. All scenarios considered assume continuing concern for local pollution

problems and the local environment, especially in developed countries but increasingly also in developing ones.

Other issues. Increasing interdependence and interconnectedness, thanks to new communication technologies, can increase the speed of knowledge transfer to the extent permitted by the degree of market openness assumed in each scenario. Market liberalisation will continue in general and in the energy sector in particular. Markets are fairly open in all scenarios although in some case this feature will be more pronounced than in others, depending on the direction taken by the two main drivers. As a result of this assumption, scenarios characterised by strong environmental concern have also a majority of countries taking action in the climate mitigation direction.

Elements that Differentiate the Scenarios

The scenarios are differentiated on the bases of two variables: pace of technological change and attitudes towards the global environment. With each variable characterised by a "high" and "low" level, four different scenarios are derived. Assuming the reference case is technology and environmental awareness that proceed along current paths, three additional cases can be analysed: the high environment, low technology case (referred to as "*Clean but not sparkling*"), the high technology but low environmental case (called "*Dynamic but careless*"), and the high technology and high environment case, referred to as "*Bright skies*". The two variables are defined as follows:

Attitudes towards the global environment. As mentioned earlier, all scenarios considered assume continuing concern regarding *local* pollution problems. *The elements that are scenario-dependent are: the extent to which attention to global pollution issues such as GHG emissions and related climate-change threats is maintained in domestic energy policy in OECD countries; attitudes towards the global environment and the extension to international energy policy. These attitudes vary from unconcerned to concerned;*

Pace of technological change. Technology continues to develop in all scenarios, and existing technology penetrates the market. However, the speed by which new technology develops and enters into widespread use varies across scenarios, from slow to fast. Consistent with the direction of the variable "attitudes towards the global environment" each scenario produces different results concerning which technologies will emerge more strongly.

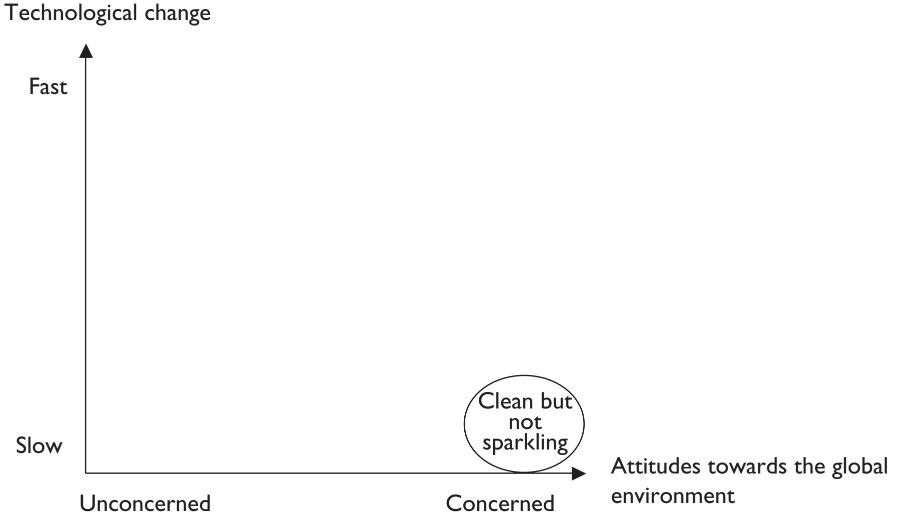
SCENARIO 1: Clean, but not Sparkling

Scenario Features

This scenario is characterised by a strong concern for the global environment by both the public and policymakers but a relatively slow rate of technological change.

Contrary to a common wisdom for which strong pro-environment policies would lead to a rapid development of environmental friendly technologies, a number of other factors could put such an outcome at risk. In this scenario a combination of pessimistic perceptions about technology and overzealous policy intervention do not allow for the full potential of technological development to be released. Furthermore, insufficient investment in R&D or failure of these research efforts to produce results leads to limited technological progress. As in this scenario technologies fail to deliver, environmental goals are largely met through induced changes in behaviour, and likely only at rather high costs.

Figure 2.2 Scenario 1



This scenario, illustrated by figure 2.2 is distinguished by its heightened concern for the global environment – particularly in connection to climate change threats arising from increasing GHG emissions from the energy sector and by acute awareness of the planetary dimension of the problem, which calls for global co-operative solutions.

A number of existing trends and situations could lead to such a scenario. Increased awareness of environmental problems could be the result of a rapid succession of extreme weather events in the developed world (something like the floods in Central Europe of summer 2002 or the unusual heat waves of summer 2003 in Western Europe) and elsewhere, or of increasing scientific evidence linking growing GHG concentrations in the atmosphere to global climate change. This change in attitudes could take place initially in the developed world, and could then spread to developing countries and take a strong hold, partly as a result of increasing wealth and attention to local issues promoting more environmental awareness. A second element is the continuing world economic growth, which brings with it increases in disposable income – which nations are more willing to spend on environmental protection. A third element is the structure of economies, which increasingly are powered by services, and a citizenry that is less willing to accept environmental excesses of industry as they are less likely to be employed in such industries or see direct economic benefits from industrial activity. Also, in the early stages of this scenario, nations could be confident on technology's proceeding effectively, and environmental benefits being attainable at low costs – thus leading them to take on stringent global environmental commitments. The changes in lifestyle that would be promoted would succeed in reducing emissions, reinforcing positively a continued emphasis on environment.

In this scenario the pace of technological change can be characterised, by comparison, as approximately equivalent to the one envisaged by the WEO 2002 reference scenario to 2030 or slower. The menu of technologies would be basically the same as in that scenario until 2050, with no new breakthroughs, although with some improvement of existing technologies. This slow rate of technological change could be the result of a weakened faith in technology as an instrument to solve environmental problems, brought about by concentration of public attention on some local environmental disasters, increased awareness of the risks of dangerous technologies in terrorists' hands, or by the food scares in the early years of the 21st century. In this scenario such half-hearted support as this for technology could result in:

- a growing view that technologies seem to have inherent and unsupportable ancillary costs (*e.g.*, for solar panels, the use of arsenides in manufacture; for nuclear power, an unacceptable level of radioactive material; and for electric vehicles a battery disposal problem);

- less bold research for radically innovative technological solutions to environmental problems;
- trends in R&D spending not much different than in the decade 1990-2000.

Poor choices of R&D investment areas in some cases could add to the problem. Partly as a result of such attitudes and mistakes, technological breakthroughs might fail to occur in spite of expenditures on research. Competing technologies may also develop, yet fragmented markets and lack of appropriate government strategies may hinder their market penetration and widespread use.

2000-2025: Riding on Good Intentions

Developed Countries

At the beginning, in this first scenario, increasing confidence in the science of climate, coupled with increasing frequency and severity of climatic impacts and a level of wealth that allows the environment to be taken as a serious priority, could cause a dramatic shift in attitudes and preferences held by consumers and citizens in developed countries. Rising concern for the global environment would translate in more environmentally friendly behaviour, increasing demand for goods and services that have a lighter environmental footprint and energy products with a low or zero carbon content. These attitudes would spur national governments in developed countries to respond to the demand for more ambitious climate mitigation policies.

The Kyoto Protocol would be followed by new agreements with additional countries taking ever more stringent commitments. Developed countries would provide assistance to developing countries, leading them also to act to mitigate emissions. For their part, citizens would be more proactive, demanding that businesses and industry produce more climate friendly products both in developed countries and elsewhere, and co-operating actively with local governments, in finding new ways to increase energy efficiency and reduce GHG emissions.

In the early part of the scenario, with political support from citizens, governments would use the full suite of policy measures to ensure the rapid achievement of visible results in emissions reductions. Policies to encourage these changes would include emissions trading, taxes on energy and energy-related emissions or externalities (like CO_2 taxes), imposed either on fuels use or on energy consumption. Domestically, fiscal

measures, standards and regulations, cap-and-trade mechanisms and voluntary agreements would be used, as well as international trading in emissions. The emphasis would be on reductions rather than trades, stemming from recognition of the need to reduce emissions sharply rather than only to meet fixed targets. Energy saving and significant shifts in fuel mix, and later in the economic activity mix would be a key part of this policy attitude. Much of this energy conservation would be achieved through successful penetration of the most efficient existing technologies and in the household sector would be the result of changes in behaviour.

Remaining subsidies on coal or other fossil fuels would be progressively removed, with more targeted support systems taking care of the social consequences in these sectors (i.e. unemployment). Green pricing schemes for renewables would be further developed. These policies to induce a shift the fuel mix from fossils to renewables would be complemented by policies to improve the energy efficiency of the system. Minimum efficiency standards on domestic appliances, boilers, electric devices, vehicles and so on, would be adopted. Standards would be supported, where necessary, by financing measures to accelerate the scrapping of old and inefficient vehicles and equipment, by lowering (and enforcement) of speed limits in highway traffic. Increasingly, urban centres especially in older cities would be closed down to private vehicle traffic, or a system of tolls for the entry of cars set up.

Mass transit infrastructure, not just in large urban agglomerations but also in mid-sized ones, would be developed to satisfy demand for mobility that would otherwise be met by private vehicles. People would choose to walk or ride bicycles whenever possible or to move closer to their centre of activity, slowing down urban sprawl and the creation of new suburbs. Average apartment size would not grow, and new houses would be actually smaller. Furthermore, some rethinking of conventional city-planning schemes would take place, especially in newer agglomerations, to minimise commuting needs. Cities would be more compact. The possibility of moving people and goods by rail (either aboveground or underground), or by river barge would be exploited whenever possible.

More stringent fuel efficiency standards for private vehicles would be introduced and periodically reviewed to tighten them further, thus accelerating the improvement of vehicle energy performance: this would apply to both gasoline vehicles and diesel vehicles. Development of hybrid vehicles would also continue, and their penetration of the automotive market would gradually increase. Bio-fuels would also be used more extensively. Gas-powered fuel cells would start being introduced in

commercial vehicles from 2008 but would penetrate the market at a very slow rate starting from existing gas distribution networks. But at least at the beginning LPG and methane use would increase in conventional vehicles and public transport fleets as well. Governments would intervene, through partnerships with industry, to promote more environmentally friendly infrastructure.

Demand in the air transport sector would continue to increase, although, due to the introduction of fuel and CO_2 taxes for jet fuel, to the optimisation of aeroplane size and to the use of lighter construction materials, fuel efficiency would improve significantly. As a result, growth in energy demand for this sector would be significantly slower.

With these measures, demand for light oil products would grow much more slowly in OECD countries, even in the presence of an increased demand for mobility. Oil will remain extremely important in transportation, but the high taxes and the draconian conservation measures taken in developed countries will significantly reduce demand growth in those areas, help prolong the life of existing oil resources and moderate the growth in prices in the world market.

In Europe, all coal power plants being retired or close to retirement would be replaced by gas turbine combined cycles, leading to a sharp increase in demand for natural gas. In North America the trend would be similar for coal plants at the end of their life: but the gas option would be preferred for new capacity as well. In nearly all OECD countries micro-generation and cogeneration in a distributed fashion would increase significantly.

Very few, new nuclear plants, if any, would be built, due to continuing attitudes of mistrust by the public towards this technology, and to concern over the long-term safety of radioactive waste storage, but the life of existing plants would be extended as much as safely possible, as a measure to contain GHG emissions.

In OECD countries, gas will be increasingly used both for power generation and in fuel cells. Increasing the number of fuel cell stacks, attractive generation capacities can quickly be reached, although the initial applications will be for distributed generation. However, on this market the competition between fuel cells and advanced gas turbines may turn out to be in favour of the latter. In OECD countries CHP generation would be used more extensively.

In parallel, public investment programmes to increase the share of electricity produced from non-CO_2-emitting sources would be undertaken.

These programmes would mostly focus on power generation from renewable sources. Minimum production targets for these sources would be adopted. Energy taxes and CO_2 taxes would be waived for renewable-based power, thus improving the economics of renewable power generation. Part of the energy and CO_2 tax revenues from conventional carbon based sources would be recycled to fund small (household or building-size) photovoltaic applications, or, in the countryside, both PV and wind generators. While the technology might not evolve rapidly, the fiscal pressures would allow existing technologies to penetrate the market.

Solar PV technology will improve its conversion efficiency but very slowly. Wind power, already competitive, will take a considerable share of the electricity market, exploiting as much as possible all good sites, provided that conflicts with other land uses do not arise. Commercial biomass use for energy production will also expand, favoured by improvements in biotechnologies. Bio-fuels, free from the problems of intermittence that characterise other renewables, will be increasingly used for power generation.

The initial emphasis in this scenario would be on energy efficiency, conservation and measures on the energy demand side and then on shifts in the energy supply mix towards renewables and gas.

The price of energy to the final consumer would keep increasing both due to increased fiscal pressure and to the increased costs of more efficient technologies for the system. This would be particularly true for the power system due to the need for back-up to protect against the effects of intermittent generation from renewables. Energy demand in developed countries as a result would be somewhat reduced with respect to the reference scenario. Also, economic growth would be more modest.

R&D spending by governments would not increase much in magnitude with respect to the trends that emerged during the last decade of the previous century (which actually marked a stabilisation at relatively low levels). Research budgets would be reoriented towards improvement of non-carbon-emitting technologies (with a focus on renewables and fusion), or towards the higher efficiency of carbon-based ones, and towards socio-economic research on policies, and approaches to induce behavioural change in a more pro-environmental direction. Chance is recognised to play a role (small or large) in determining the success of R&D efforts. As one of the assumptions in this scenario is that technological change is slow, efforts spent on basic science and long-term research on innovative concepts would yield little practical result.

Large deployment programmes in renewable generation would set in motion technology learning in the production of parts and components for renewable power plants, bringing down costs over time, and improving the efficiency of energy transformation. But this process would be very slow. Also, investments in R&D to improve the efficiency of renewable technologies and electricity storage technologies would be made, in order to deal with the problem of intermittence of power supply that characterises solar PV, wind and other intermittent technologies. However, the results of this R&D activity in terms of increased transformation efficiencies of these technologies would not live up to expectations, and renewable energy technologies, especially for power generation, would remain unable to supply a sufficiently large share of the market. Fusion research, meanwhile, would continue, but with limited progress.

In addition, in the first two decades of this scenario, R&D investment on technologies such as nuclear and carbon separation and sequestration would be weak. In a world of heightened concern for long-term environmental risks this could be itself the result of pro-environmental attitudes. It could be an essentially political choice based on the fact that these technologies either pose serious security problems (long-term safe storage of radioactive waste or ocean storage of CO_2), or are viewed as temporary solutions (terrestrial CO_2 storage), rather than being the result of an economic choice. In the case of carbon sequestration, some research would be still carried out by oil and gas companies as a way to boost recovery rates from hydrocarbon deposits and the technology would consolidate. But progress would be much slower for technologies of aquifer sequestration and even more for ocean sequestration due to concerns about environmental risk.

The Kyoto targets for the first commitment period would be attained. OECD countries would then adopt even more stringent emission reduction goals. With economic growth resumed in Eastern European countries and Russia, very little (if any) hot air would be left for emission trading, which now would have to be based on actual emissions reductions. To meet the new goals more policy intervention would be needed.

As a result of the environmental efforts made, environmental quality, and particularly air quality in large metropolitan areas in developed countries would improve significantly, reducing the incidence of respiratory diseases, and reducing water and soil contamination from airborne pollutants. Marine pollution would decrease too, owing to reduced oil tanker traffic.

Developing Countries

As a result of strong leadership and motivation (initially by a small group of developed countries), and of increasing incomes, environmentally conscious attitudes would gradually spread to all developed countries and to many of the emerging economies in the developing world. This would lead to a more proactive stance by governments vis-a-vis environmental protection including climate change mitigation.

The most dynamic and fast growing among developing countries, already plagued by increasing problems of local environmental pollution, would start also appreciating the risks of global climate change and show a willingness to participate in efforts to avert them.

Firstly, they would try to deal with the problem of air quality in large urban agglomeration and in industrial areas. This they would try to do by a tightening of air quality and vehicle emission standards and a gradual shift from coal to gas or heating oil for household consumption. Bus and taxi fleets would be massively switched to LPG and methane. This would help improve the situation of air quality even in a situation of growing energy demand.

Cautiously, developing countries would also start accepting the idea to take gradual commitments for GHG emissions growth limitation and later for reduction, as they climb the economic development ladder. Some countries would adopt emission control commitments by 2020. This effort would be fostered by increased willingness by developed countries to help with technology transfer and financing of GHG emission-reducing projects. Partnerships would develop and many projects would be carried out in the framework of CDM-type of mechanisms. The availability of financial resources from developed countries might not be very large, as the latter would be already investing domestically in non-carbon-emitting technologies, paying high energy prices, and later experiencing as a consequence slightly slower economic growth. Resources, however, would be available and growing, often also as development aid for education and health programmes.

Oil demand will keep growing in developing countries, driven by income growth and by increased appetite for mobility in these societies. In fact, before the impact of conservation measures and of technology improvement on oil consumption is felt in those countries, some bottlenecks in oil supply may have emerged. One of them concerns the refining capacity installed to produce light distillates and particularly

products that comply with higher environmental standards (low sulphur, etc.). But another bottleneck may be linked to political instability in some of the supplying regions.

Faster growing developing countries like China, India, some countries of South East Asia, would become large importers of natural gas, although coal reserves, where present (e.g. in China and India), would still be used to satisfy a large part of domestic demand especially for power generation. In coal-producing countries new generating capacity would still to a great extent be coal-fired but use cleaner technologies. At the beginning they would build pulverised coal plants then fluidised bed combustion plants or supercritical plants with pulverised fuel; later on they will move to pressurised-fluidised bed combustion plants, coal gasification and combined cycles or to ultra-supercritical plants which developing countries would then start to adapt to their own needs and later improve and develop themselves. Gas-based generation would develop in parallel, showing rapid increases especially in the first 20 years.

As a result of greater emphasis on the local and global environment, demand for natural gas would grow very rapidly in developing countries as well, straining existing resources. New gas exploration activities would have to be undertaken. Huge financial resources would be needed, particularly to build new gas transportation networks (pipelines and LNG terminals). By 2020 the geopolitics of gas will become as central to world growth as the geopolitics of oil was in the last 30 years of the previous century. Prices will have increased considerably even in the absence of conflicts.

China and India will try to assure long-term supply contracts from gas exporting countries like Iran, Russia and Central Asian Republics, by forging strategic partnerships with those countries. The reciprocal economic interest in doing so might help stabilise politically the supply areas.

Similarly, in Latin America, although in a situation of economic growth less dynamic than in Asia, demand for gas will grow rapidly, promoting more exploration and accelerated construction of pipelines. Prices would go up following increased demand both in Latin America and in North America. Africa, the slowest growing area, will remain for some time an exporter of gas. World wide, the times in which associated gas from oil deposits was flared will be long gone, both for environmental reasons and for the increased value of gas.

Gas will largely play the role of transition fuel while non-carbon alternatives are developed worldwide. In parallel, non-carbon and low- or zero-net-carbon technologies will be increasingly adopted and developed.

Some of the largest and most populous developing countries would pursue, in parallel, the nuclear option, initially with technology supplied by developed countries, but increasing also developing their own design. Some nuclear plants would be built in China, India, Brazil, South Africa and a few other countries, although construction programmes would not be massive.

Renewables like solar PV, wind and biomass, do not see dramatic technological improvements or cost reductions from accelerated adoption measures in developed countries. But due to environmental preferences of developed countries and favourable financing terms offered by them, renewables are pushed through the market and start to expand rather fast in developing countries too, where the renewable resource potential is much larger. More conventional renewables, such as hydro, will be also exploited to close to their maximum potential, even amid increasing opposition by displaced populations and environmentalists.

Solar PV technology only slowly will improve its conversion efficiency, and thus costs will decrease equally slowly. However, wind power, already competitive, will take a considerable share of the electric market wherever wind conditions are good and conflicts with other land uses do not arise. Commercial biomass use for energy production will also expand, favoured by improvements in agricultural practices and in biotechnologies. Bio fuels, free from the intermittence problems that characterise other renewables, will be increasingly used for power generation, but their use will also be expanded as fuel additives to power vehicles.

2025-2035: a Time of Growing Economic Constraints

Over 25 years, considerable environmental benefits would have been achieved. In addition, the policies would lead to changes in lifestyles – with trends in developed countries towards lifestyles that value education, leisure, culture and the arts more than the current measures of economic performance and material wealth. Productive activities would be less material-intensive and more labour-intensive. Developed countries would have already completed the transition towards a mostly service economy, contributing to a significant reduction in energy intensity.

While global emissions would be approaching stabilisation, reductions would not be occurring, and evidence of global climate stresses would keep increasing. Concurrently, the economic costs of climate mitigation policies would start to be felt, for the level of technological improvement needed to bring down or control the costs of further decreases in GHG emissions would not materialise rapidly enough. Further reductions in per capita energy consumption in OECD countries would become increasingly difficult. Higher energy costs would be another cause for sluggish economic growth, already driven in most of the OECD countries by several other factors such as ageing of the population, rising social security system costs and somewhat more regulated markets. Stresses due to slow economic growth and relatively high unemployment would increase the difficulty in maintaining the desired level of development aid spending and of investment in new but still expensive technologies.

In the meantime, progress with respect to the planned GHG emissions reduction trajectory would start to slow down in OECD countries. Insufficient investment in basic R&D and/or a focus on technologies (such as fusion, or power storage) that over time have been incapable of maintaining their promise will have led to a substantial lack of adequate technological options. By 2025 this would cause a reassessment of some of the technology choices made to achieve environmental goals. At the end of this reflection period, developed countries would emerge with a somewhat more sober view of the possibility of achieving ambitious environmental goals without using all available technologies.

On the other hand, economic growth in developing countries in the first half of the new century would have continued. A number of developing countries would be skipping altogether the heavy industrialisation phase; however, others would be characterised by a strong industrial sector and still increasing per capita energy consumption. While continuing to drive up emissions and environmental pollution, this growth would also bring with it a growth in environmental concern on the part of a large share of the population, and the increasing financial wherewithal to start environmental protection programmes in those countries. Strong movements to protect the remaining forests and wildlife species would develop not just in China, India, Brazil and South Africa, but also in Indonesia, all of Central and Latin America and even in parts of Sub-Saharan Africa. Besides the creation of an important number of parks and natural reserves to protect what is left of their natural heritage, this would lead to an increasingly active role by governments in developing policies to deal with global pollution issues, including marine pollution and, most of

all, climate change. The effects of climate change by that time would also be increasingly felt in developing countries, and the devastation wrought by tropical storms, successive droughts and destructive rains would bring misery to most vulnerable areas. This would mobilize the energies not just of the intellectual elite, influenced by the new values of the developed world, but also of ordinary citizens to demand that action be taken. To the many that never had access to luxurious, energy-devouring lifestyles, as long as incomes are able to satisfy basic needs, the accepting of ideas of respect for the environment may come as a very natural process. Attitudes in developing countries towards the environment and the possibilities for action to prevent climate change would become more positive.

2035-2050: Pushing Ahead

By 2035 most if not all developing countries will have adopted greenhouse gas emissions control targets. In a number of cases these would be explicit emission reduction commitments, in others they would aim to moderate emissions growth. Their governments would adopt policies and plans aimed at achieving those targets. Furthermore the productive activity mix in many cases would not be very energy-intensive, or would have already evolved towards less energy intensive patterns.

However the technology stock, depending to a large extent on research and development taking place in developed countries, will not have dramatically improved in the first 30 years of the century. Many newly developed countries would depend on an energy infrastructure put in place in the first 15 years of the century, using already tried and tested technology of the time, but with a perspective of 15-20 years of useful service ahead. This capital stock could not be scrapped ahead of time, seriously limiting the possibility of controlling emissions without sacrificing further growth.

New and advanced technologies developed in the rich countries would not be sufficiently advanced to offer "miracle" solutions for carbon-free energy supply. Many renewable technologies would still be unable to provide energy and power on a large scale. Other fossil fuels-based power technologies will be reaching maturity but remain very important sources of GHG, especially once the efficiency losses of SO_x and NO_x abatement equipment are included.

As a result, in order to maintain some of the commitments to reduce GHG emissions growth, some newly developed and developing countries will reconsider technologies such as nuclear and carbon sequestration that they had rejected earlier.

While a resumption of nuclear programmes may be difficult in many OECD countries due to the loss of technological capability (nuclear engineers, skilled workers, manufacturing capabilities), things would be different in countries that had never totally abandoned nuclear production and in some of the developing countries. In the latter, nuclear would remain a strong alternative way to reduce emissions while meeting ever-growing electricity demand. More favourable economic conditions and growing concern over climate change would overcome local environmental risks. As a result, even without a substantial improvement of the technology, it will be increasingly used. Without repeating the gigantic plant construction programmes that took place in some OECD countries in the 1970s and 1980s, significant nuclear programmes will be started in a number of developing countries, and will privilege smaller size and safer plants.

Carbon capture and storage technologies would also be reassessed. While substantial experience would already exist for sequestration in hydrocarbon deposits (and plenty of exhausted ones), some of the other options would be explored, leading to some improvement of the technology towards the end of the period. But for some time considerable resources would have to be invested in carbon separation and capture research, by far the most costly segment of this process.

Widespread use of most efficient technologies in energy end use, although not very innovative with respect to present standards, would help moderate energy demand growth. In many parts of the world the structure of urban agglomerations will have become denser or (for the newest ones) adopted decentralised patters, easing commuting problems. Public transport would be preponderant in OECD countries. Efficient diesels, hybrid vehicles and (to a lesser extent) hydrogen-powered fuel cell vehicles will help keep oil consumption low.

As a result of a combination of the use of the above technologies (on both the supply and the demand side) and a continuing shift in behavioural patterns towards less consumerist lifestyles, by 2040 the global GHG-emission curve would be actually starting to bend down. Energy consumption patterns between developed and developing countries would be heading towards convergence, but this will also have been achieved at a cost of lower income growth and a substantial reduction of per capita energy consumption in developed countries, while a moderate increase would have taken place for developing ones.

The outlook for 2050 shows a world that is labouring to further reduce GHG emissions, aiming at stabilising their concentrations but doing so at the cost of lower economic growth and of relatively important behavioural changes – some easy to accept, others perhaps less easy to live with.

SCENARIO 2: Dynamic but Careless

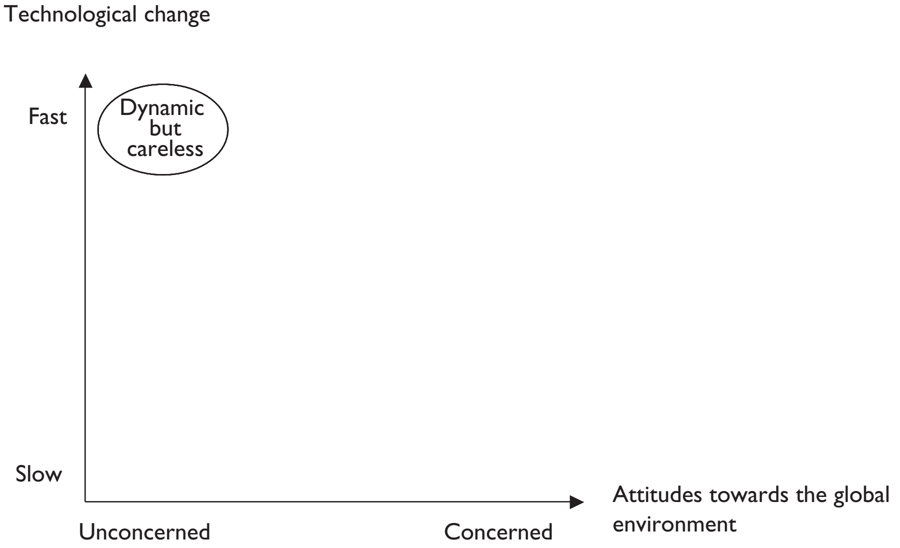
Scenario Features

This scenario is characterised by very dynamic technological change, low priority for climate change mitigation and a generalised belief that sustained growth and rapid progress in technologies will take care of all problems without need for much policy intervention.

As a corollary, this scenario has more rapid economic growth than the first one, including more open but less regulated markets. Unhindered economic growth is the main priority, shared by developed and developing countries alike. However, not all countries are able to achieve fast growth rates and some lag behind. Global threats such as climate change take a back seat in the concerns of both citizens and politicians. Although energy represents a relatively small share of production inputs or household spending, low energy prices and security of supply are considered an important condition for economic growth.

At the beginning, progress is faster in fossil fuel based technologies, helping to maintain low prices. In both developed and developing countries local environmental problems are not ignored but are dealt with at the local level and consistently with the economic resources of the affected communities or individually through pollution impact averting behaviour. As a consequence of these initial conditions, fossil fuel demand grows rapidly, followed by an increase in GHG emissions. These two factors increase the likelihood of energy security of supply crises and worsening environmental conditions. To deal with security of supply, and in the continuous quest for low energy costs the system accelerates the development of new technologies. While the first phase of this scenario is therefore heavily oriented towards fossil fuel-based technologies, in the second part of the scenario horizon, non-fossil technologies emerge too.

Figure 2.3 Scenario 2



In this scenario too (see figure 2.3), the Kyoto Protocol goes into effect but efforts to reduce climate change are not carried forward to a second commitment period. The short-term costs of action are deemed too high for additional commitments in the near term, and the various groups whose vested interests might be affected are much more vocal that those who might benefit from, say, energy savings, carbon tax revenue recycling or, more directly, climate change mitigation. Cost uncertainties and cost controversies remain. As a result, the international process is unable to reach agreement on the next steps that satisfies a diminishing interest in the problem from developed countries or the concerns that any actions would hinder the economic growth of the developing world.

Both developed and developing countries focus on economic growth. Overall, this scenario has a slightly faster economic growth rate than the Clean but not Sparkling scenario described above; it also has more open but less regulated markets. With the emphasis on economic growth and increasing income, lifestyles become more consumerist, driving up households' energy consumption too. However, economic growth is not homogeneous: some countries grow fast, others lag behind. Income inequality across countries remains high or increases, creating potential conflicts.

Security is a looming problem, and particularly security of energy supply, both at the local and at the global level. Governments are less

interventionist (they do not intervene at all in matters of global environmental concern), but still they make significant investments in basic research. Technology development and pre-commercial R&D are mostly left to business enterprises, which use them to acquire a competitive edge in the market. Technological change is vibrant in all sectors. Throughout the period, in the energy sector technological progress is mostly driven by cost and security of supply considerations; particularly at the beginning, it is faster in supply side technologies and especially in fossil fuel related technologies.

2003-2015: Abundant Energy Resources

Lacking the constraints of carbon-emissions reduction, this scenario is heavily based on fossil fuel sources of energy (coal, oil, and gas). At the beginning of the scenario period, fossil fuel resources are abundant: oil reserves are estimated to last about thirty years at present day consumption rates, while gas reserves, by the same criterion, could be sufficient to satisfy demand at least until 2050. Undiscovered resources and non-conventional sources of both oil and gas have the potential to meet future demand for longer periods. Concerning coal, reserves are huge when measured against the current consumption rate.

Geographic distribution of fossil-fuels resources, however, is more problematic. While coal reserves are widely dispersed across continents, oil and gas resources are more concentrated geographically, with more than half of proven oil reserves and over a third of gas reserves concentrated in the Middle East and additional large reserves localised in the former Soviet Union. The former area is politically troubled and the latter is not felt entirely secure with respect to their relationship with the OECD countries, which adds further uncertainty to the large production infrastructure investment needed to expand their supply potential.

In this scenario the goal of low energy prices, especially for fossil fuels is pursued in several ways: sustained investment in new exploration, extraction and processing technologies, increased competition among producers, but also increased control of those important energy-producing areas that remain politically unstable. In this scenario, the initial emphasis is on the supply side of energy and on supply side technologies. However technological progress after a while catches-up on the energy demand side as well.

Developed Countries

As a general remark, valid both for developed and developing countries, in the first decades of this scenario, except for those areas where large hydrological resources are still unexploited, new (and replacement) power generation capacity would be mostly fuelled by coal and gas and (marginally) by oil products. At the beginning, the precise mix of these sources would be dictated almost exclusively by direct cost considerations: local availability of resources, market prices of resources, transport cost and plant construction costs.

However, in developed countries the cost of abatement of those air pollutants that have a local or regional relevance (SO_2, NO_x, particulate, etc.) have to be taken into account in the power plant costs. This type of consideration may favour gas over coal-fuelled generation in a significant number of cases. While global issues are of little concern, populations are increasingly aware of local health impacts or of such environmental damage as caused by acid rain and particulates and have come to expect that these noxious consequences of energy production be brought under control. As CO_2 emissions represent little direct health hazard, virtually no effort is made to control them.

At the beginning, nuclear power is an expensive option, especially when issues of plant decommissioning and storage of radioactive materials are fully taken into account. However, continued research funding to address the cost and the security issue, leads to results that improve the economics of this technology, spurring the resumption of nuclear programmes in some developed countries later, around 2020.

This scenario privileges centralised options for power generation, as in general they allow for larger economies of scale and lower costs. However decentralised generation is not excluded *a priori* if it can compete effectively on a cost basis, and especially as a tool to address security of electric supply in particularly sensitive applications.

In the industrial sector in developed countries gas will maintain a strong role for all heating and process-heat needs. Use of light oil products will continue but decrease. Coal will remain important only in steel and metallurgical industries. However, increasing interest, in some countries, will be paid to capture and storage of criteria pollutants from coal burning. Electricity will take an increasing share in all sectors, as automated and computerised processes become the rule.

Gas demand would grow in the residential/services sector for water and space heating or for cooking, where its relative cleanliness will make it the fuel of choice. This growth will take place as a result of gas distribution grids being completed and increasing incomes leading to higher demand for larger apartment size by households. The increasing number of households with only one or two members accentuates the trend. In fact these two factors and the increasing appetite by individuals and households for more space, higher levels of comfort, for more electrical equipment and electronic devices will rapidly push up demand for other energy carriers, notably electricity in the residential sector. Similar considerations would apply to the commercial sector.

In the near term, oil products would remain unchallenged as fuels of choice in the transport sector, with their demand growing very rapidly world-wide due to increasing demand for mobility.

The trend, particularly for road transport, would not be as fast in OECD countries as in the rest of the world, with Western Europe showing the slowest growth due to increasing traffic congestion and progressive vehicle demand saturation. But preferences would remain oriented towards bigger and faster vehicles (SUVs and luxury cars) although their fuel efficiency would improve over time. The average household in OECD countries would own two cars, although congestion and parking difficulties would promote the use of smaller, more compact and much more efficient (certainly less polluting) city cars. Passenger transport by rail would maintain a market for inter-city travel, in fast trains connecting large metropolitan areas.

Air travel (both for business and for tourism) would keep increasing in OECD countries, as per capita incomes keep increasing. People in developed countries take long weekend vacations more often to destinations abroad while increasing the spatial range of their tourist trips. However, fuel efficiency of the fleets will continue to increase, partly as a result of improved occupancy rates and partly due to increased aeroplane size. Freight transport would be still handled mostly by road trucks, and increasingly by air cargo, often as a result of growing electronic commerce.

Developing Countries

In developing countries economic considerations in deciding the specific fuel/technology mix for power generation will be of paramount importance. This implies that fossil fuels and conventional fossil fuel-based technologies will be preferred in most cases. In coal-producing countries,

coal will satisfy a large share not only of power generation but also of industrial energy needs, all processes requiring heat.

As mentioned above, in this scenario developing countries do not get involved in the Kyoto Protocol and CO_2 emissions reduction is not a relevant policy objective. Concern for increasing emissions of local pollutants (SO_x, NO_x, particulate matter) will increase at a later stage as average per capita incomes grow. However, in countries with a high hydrological potential, this resource will be obviously exploited, especially if adequate financing from international lending institutions is available.

While not an interesting option at the beginning of the period due to its large capital requirements and high system costs, by 2015 nuclear programs are actively being pursued in those energy resource-poor developing countries where income growth and energy demand growth are more sustained.

Fairly large and geographically concentrated potential demand will be a precondition for large investments in gas distribution grids to be started in developing countries. As soon as these investments are realised, growth in gas demand will be very rapid in the household sector especially in large cities, increasingly replacing coal or other solid fuels, or heating oil, in order to mitigate local air pollution problems. And its role will be increasing in industrial uses as well, especially in areas where the presence of industrial activities is more concentrated.

Oil products demand in the transport sector will grow very fast due to increasing affluence and increasing demand for mobility. This demand would be particularly robust in Eastern and Central European countries, Russia, Asia, and Latin America.

Developing countries at the beginning would try to catch-up with the same transport demand patterns and behavioural models of industrialised ones. In most cases the construction of an important railroad infrastructure (as done by rich countries in the early days of their industrialisation) would not be considered interesting, and priority would be given to road infrastructure.

Air travel (both for business and for tourism) would keep increasing in the fastest developing countries as per capita incomes grow. For those countries fuel efficiency of the fleets will increase especially in the newest ones. Poorer countries will continue using older planes and older technologies. Domestic freight transport would be done mostly by road so truck transport will experience explosive growth. Air cargo transport of goods will also increase.

2015-2030: Supply Security and Environmental Challenges

As a result world oil demand would grow fast (over 2% per year). By 2015, tensions on the oil supply side would have become considerably exacerbated. Initially they would concern sporadic shortages in refinery capacity in developing countries. But with demand booming, investments in new capacity in many cases would catch up. Traditionally oil-exporting countries would, at last, massively enter the refining business but large refining capacity will also be built in rapidly industrialising countries. In addition, some delocalisation of refining from developed countries due to increasing environmental regulations and pollution control costs could take place.

At those rates of oil demand growth, the rate of resource extraction would also accelerate. This would not show up immediately in a price increase, because strong demand would sustain robust investment by the oil industry in new technologies to find and extract oil in increasingly difficult conditions without dramatically increasing costs. This and fierce competition among oil companies will prevent prices from increasing for some time. This process of adjustment in the oil market would take place rather smoothly until 2015. But eventually prices will start to creep up as a result of increasing resource exhaustion. Furthermore the high cost producing areas would yield to those supply areas with lower costs and larger reserves, determining an increasing import dependence on a few geographic regions, and increasing supply security issues.

As a result of robust growth in world gas demand (between 2.5 and 3% per annum), driven particularly by developing countries, and of increasing resource extraction and transportation costs, gas prices will also increase gradually. These price signals, if properly transmitted to both producers and consumers, in turn will drive technological improvements both in supply and demand, ensuring that the price increase is contained. For gas, competition with coal will be another element of moderation.

Security Risks

However, increasing import dependence from a few important geographic areas constitutes an inherent security risk, both for oil and for gas, especially if political stability is not ensured in those areas. Strong nationalistic feelings would re-emerge in those regions, creating tensions. Producing countries would start to complain about low resource prices, prevailing until then; uneven distribution of the oil and gas revenues would add to social tensions. The need for oil and gas pipelines to cross many

state borders (often in areas where conflicts simmer) before reaching their demand terminals would be a continued source of risk, reflected in the cost of financing new infrastructure. Insecurity of shipping lanes in South East Asia could become an additional source of tension and oil or LNG price volatility in the area.

Countries that have become increasingly dependent on imported resources would develop more and more aggressive policies to secure a steady flow of supply. When conflicts appear, supply side shocks and price spikes will take place too. This type of event will take place with increasing frequency.

In this scenario, this increasingly tense political and energy market situation would likely bring along a recrudescence of terrorism and an increasing preoccupation with security at many levels. As a result airline traffic growth would suffer from periodic crises, and tourism too would be affected; the security of industrial installations as well as that of networks (in transport and communications) would be reassessed and at all levels technologies that improve security would receive additional impetus.

Although not caused by a pressing scarcity problem, these crises will induce energy-importing countries to reassess their overall security of supply strategy. The technology options to reduce energy dependence would be considered, prompting an acceleration of technological change in various directions.

One of them would be a rapid improvement of coal gasification and liquefaction technologies, which would allow, through synthesis processes, the cheaper production of increasing quantities of the preferred energy carriers without requiring significant changes in end-use technologies. This might be the strategy chosen by China and perhaps India as well, although the US would bring a strong initial contribution to developing this technology. Australia and South Africa would also invest (and might actually become leaders) in coal gasification and liquefaction technology.

Another direction would be rapid development of technologies that allow the successful exploration and exploitation of increasing quantities of oil and gas from very deep deposits or from unconventional sources (tar sands, oil shales) in politically more stable areas. Canada could thus strengthen its energy-exporting role. The idea of exploiting methane hydrate resources would also receive more attention.

A third approach would be the development of more efficient energy transformation and end-use technologies. In the era of low energy prices these technologies had been neglected by consumers and thus had little

room to develop, but with increasing or volatile oil and gas prices, they would be looked at with renewed interest.

Finally, backup systems, as a strategy to increase security in case of supply interruption, terrorist attacks or system failure would be increasingly maintained at hand, creating a certain amount of excess capacity in sectors like power generation and increasing the diffusion of distributed generation.

Increased investment in energy efficiency would take place mostly in those technologies that use oil products, or gas or that use electricity in countries where gas represents a substantial share in the power generation mix. Pervasive use of information and communication technologies will increase the scope for energy efficiency improvement in all demand sectors. Improvement would also concern technologies that produce electricity from gas. These technologies, therefore, besides power generation, include the entire transport sector, nearly totally reliant on oil products, as well as the industrial and residential sector. In particular, they would include fuel cells powered with both natural gas and other fuels, especially for transport applications, as they provide greater fuel efficiencies than internal combustion engines. By 2025 fuel cell cars will represent a significant share of the market for new vehicles in developed countries. Conventional and hybrid vehicles would also be greatly improved allowing for spectacular reduction of fuel input per passenger/Km travelled.

All of these directions of technological improvement could be successfully pursued in parallel: in fact they would present the same advantage, namely, improving security of supply through diversification of sources without requiring significant changes in new infrastructure and end-use technologies.

At first, with keeping costs down a high priority (and with the continuing low priority assigned to global climate change), nuclear technologies will start being reconsidered in those developed countries with high energy demand, strong dependence on foreign energy and no significant domestic resources of coal – and even then mostly as a measure to mitigate energy supply vulnerability. Thus, for example, Italy may move toward a nuclear approach only after a lengthy period, while Japan and France would never discontinue their current nuclear programmes. Later, nuclear plant construction programmes would resume in other developed countries too. Meanwhile, with continuing high costs, the attention towards certain renewable technologies like solar PV will remain modest,

but investment in the cheapest renewable options (wind, biomass and hydro, where possible) will increase.

Environmental Stress

Over time, rapidly increasing consumption for fossil fuels will have led not only to accelerated depletion rates, but also ever increasing levels of GHG emissions, particularly CO_2. The underlying assumptions and drivers of this scenario make it a "carbonisation" scenario. Due to the continuing strong use of oil and the dash for coal, energy related CO_2 emissions will have increased even faster than energy demand, inverting the trend that prevailed in the last thirty years of the previous century.

Furthermore the environmental impacts of developing the oil, gas and coal industries at such a magnified scale would be huge. The land and marine pollution resulting from exploration, extraction and refining activities, not to mention transport of hydrocarbons and coal, would be significant and only weakly mitigated by improved environmental protection practices and technologies. The latter would be mostly available to richer countries, but poor developing countries endowed with fossil fuel resources might experience significant environmental degradation. As they too get rich, they will become more sensitive to local environmental issues and ask for cleaner technology solutions.

Among other reasons for the push towards cleaner technologies would be transport-related air pollution in large cities. Even in developed countries, air quality in large cities would deteriorate due to the increased use of cars. Although new generations of vehicles will produce small quantities of very fine particulate, their presence in urban air will be increasing. Atmospheric ozone concentrations would have reached very high levels, especially in summer days, and the presence of volatile organic compounds would increase. These pollutants would become responsible for an ever rising frequency of respiratory diseases and of cancers in the population. The situation in the mega-cities of the developing world would be much worse.

To respond to the local pollution concerns, new technological solutions would be sought, both in power generation and in the transport sector. This push will reinforce some of the technological changes prompted by security of supply crises and strengthen the rationale for specific technology solutions.

2030-2050: a New Stage of Technological Development

In this framework, nuclear power receives a boost almost everywhere, not just because it can mitigate security of supply issues in the gas market but also as it represents a technology that allows large-scale power production without emitting local pollutants. In addition, hydrogen produced through reforming from hydrogen-rich gases of fossil origin (natural gas, or synthetic gas) would become an important energy carrier.

As mentioned, hydrogen presents the advantage of being a rather clean fuel when used in fuel cells to produce electricity or heat: its only by-product would be water. Air pollution problems in cities could be substantially mitigated by use of fuel cell powered vehicles and of fuel cell power plants. Hydrogen could also function as an energy storage medium. Hydrogen itself could be produced in several ways from fossil sources, including:

- steam reforming of natural gas;
- coal gasification; and
- residue or coke gasification.

All three technologies would be already available at competitive prices, but with high gas demand and gas prices higher than coal's, the second option is likely to be cheaper. Thus hydrogen could be produced close to coal-mines, and likely in large centralised plants.

Furthermore hydrogen could be produced by electrolysis from off-peak electricity generated in nuclear plants: following a resumption of nuclear programs in various parts of the world this would also take place, although not necessarily on a massive scale. In a fast technology development world, other ways to produce hydrogen, using biological agents (microbes) might also be developed. However, efficient ways to concentrate it, to increase its energy density, and to store it for fairly long periods (days or months) would be needed. Technological developments in this area would benefit from research and rapid process in materials science and basic chemistry, aided by continuous improvement in the knowledge of how living organisms manufacture at the molecular level materials possessing special properties.

The fuel cell technology, especially for mobile applications, would have developed faster after 2015-2020, as a way to improve energy efficiency,

but still using on-board reforming of carbon-based fuels. By 2030 the technology could use hydrogen produced elsewhere.

As hydrogen production and use is increased, an appropriate distribution infrastructure would be put in place to deliver the hydrogen in the consumption markets. However, small scale, decentralised production of hydrogen (e.g. from gas reforming, which would allow continued use of the existing gas grid) would in many cases be the preferred solution.

Until 2040 in this scenario there would be no real incentive to promote large scale sequestration, as it only results in emissions abatement while not increasing energy security or economic efficiency as may do renewable, fuel switching, nuclear or energy efficiency improvements – on the contrary, the energy cost of capture may even increase the concerns about energy security. However, CO_2 re-injection would be increasingly utilised to increase oil and gas recovery rates. But increasing use of coal for hydrogen production would start posing problems of CO_2 emissions, and coal-mine storage technologies would be developed and deployed at some sites.

Over the previous period renewables would have evolved only slowly (this being a scenario that prioritised low cost and did not place any weight on limiting GHG emissions), mainly for enhancing energy security and energy access in remote areas. Wind technologies would have survived in the best sites and in some market niches, but solar PV would not have improved much. High temperature solar thermal applications for electricity generation would have slowly developed to reach fairly high conversion efficiencies and attractive economics. They would be ready for larger scale adoption.

As a longer-term option, the fusion reactor technology may well move closer to commercial application under this scenario. In a relatively higher economic growth, fast technological change scenario, there could be resources for governments to invest over long periods in a rather expensive technology such as fusion. But it is unlikely that the technology would be already at the prototype stage for commercial power plants production by 2050.

Over time, the drive to improve energy efficiency both in end-use technologies and in energy transformation initiated after 2025 would start bearing fruit and the efficiency of the system would be already greatly improved by 2040. Continuing this progress in energy technologies would also make good economic sense, especially when local environmental problems were factored in.

Development on a large scale of the energy options illustrated above would lead to an improvement of local air quality in both developed and developing countries and even to a significant slowdown of GHG emissions growth in developed countries, gradually spreading to developing ones towards 2050. Over the period, this scenario would produce much higher emission concentrations than the first one – but may create the technological conditions for more rapid reductions beyond 2050. Adoption of these new technologies would take place as they become increasingly competitive, and in light of their clear superiority in terms of cleanliness. In the case of hydrogen this advantage would be coupled with comparable ease of use with respect to conventional energy carriers.

SCENARIO 3: Bright Skies

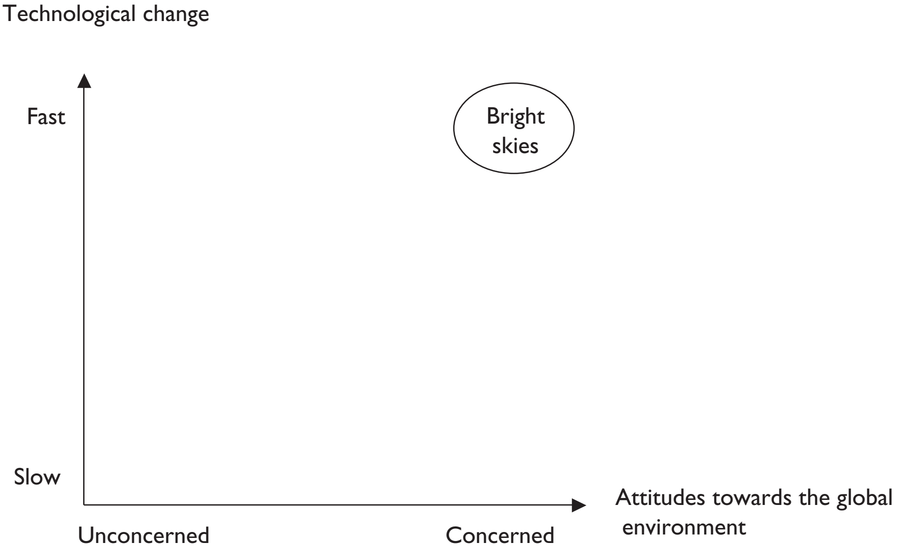
Scenario Features

This scenario is characterised by both rapid technological change and strong concern for the global environment by both the public and policymakers.

Other features of this scenario include a (global) GDP growth rate somewhere in between the first two cases but closer to the second, robust trade and market liberalisation trends, a narrowing down of income differences across regions and countries. As a result, overall, energy prices will be somewhat higher than in the second scenario but lower than in the first.

In this scenario, governments of developed countries agree to deal with the threat of climate change in a co-ordinated fashion and to take action to slow down and reverse current trends in GHG emissions. In due time they are joined in this process by developing countries, who agree to take increasingly stringent commitments for GHG emission control and reduction. Domestically, developed country governments set out to design and implement policies that will, on the one hand, encourage a reduction of energy-related GHG emissions and, on the other, channel both government and private resources towards development of new technologies for climate change mitigation. These efforts produce a host of positive technological outcomes, which allow the attainment of environmental goals, and also enhance energy security while keeping prices relatively low.

Figure 2.4 Scenario 3



In this scenario (figure 2.4) as in the first one, increasing awareness of global climate threats coupled with increasing frequency and severity of climate impacts, feed a growing attention to climate change issues by the public and the governments. Public support for action is fuelled by a widespread view that technology options will keep the cost of mitigation relatively low, and optimism that ancillary benefits of GHG reduction will also lead to both enhanced energy security and a strong multi-lateral system that promotes trade and reduces conflicts. This attitude has several implications. At the individual level it translates into more environmentally friendly behaviour, increased demand for goods and services that have a lighter environmental footprint and energy products with a low or zero carbon content. At the collective level this attitude spurs national governments (first in developed countries and subsequently in the developing world) to respond to the demand for more ambitious climate-mitigation policies. Businesses take into account these new preferences in product design and particularly in the type of energy services provided. Near-term success in both technology development and GHG reduction reinforce this trend.

In this scenario, governments of developed countries deal with the threat of climate change in a co-ordinated fashion and take action to slow down and reverse current trends in GHG emissions, so as to stabilise concentrations at a safe level before the end of the century. They are

aware that developing countries will only slowly begin to commit themselves to emissions reductions, but agree to go ahead with a concerted effort themselves first. Simultaneously, they pursue through multilateral diplomatic processes the goal of substantial participation of developing countries in the emission control effort. Developing countries are supported by financial assistance and, in the interest of maximising industrialised countries' technology export markets, through technology-transfer programs and assisted trade agreements. This gradually leads developing countries to become involved in the process, initially by accepting rules to control the increase in their GHG emission and later by agreeing to reduce them.

Overall, in this scenario the pressure on fossil fuel energy resources would be much mitigated with respect to the Dynamic but Careless scenario. Oil use in the developed world would grow at a much slower rate, thus dampening potential tensions in the market. Coal use would decrease in industrial countries both as a share in primary energy and in absolute terms while it would increase but at a much slower pace in developing ones. However, the exploitation of gas resources would be probably more intense than in the Dynamic but Careless scenario, leading to increasing prices.

This scenario would likely have a slightly slower growth rate of global GDP than the Dynamic but Careless scenario. Growth would be slower at the beginning in developed countries, due to the increased costs of providing energy in a more environmentally compatible way. However, as the system responds and technology advances, the net increase in energy prices may not be that big. Furthermore, technological innovation by creating successful new industries and environment-friendly products would foster new economic growth.

2003-2025: Lowering the Emissions Curve

Developed Countries

Urged by public opinion, alarmed by scientific and media reports that climate change is taking place faster than previously predicted, developed country governments accelerate efforts to mitigate GHG emissions growth. They start by designing and implementing new domestic policies that will, on one hand, encourage a reduction of energy-related GHG emissions and, on the other, channel both government and private resources towards development of new technologies for climate change mitigation.

Governments deliberately use a multi-tiered policy approach, with short-, mid- and long-term measures, targeting both the energy demand and the energy supply sides. In the short run, policies aim to reduce energy use and promote efficiency in both energy demand and supply, thus reducing emissions. Energy-use reduction and greater efficiency are pursued through price measures (energy and environmental taxes), through grants and subsidies for the use of best available technologies, through cap-and-trade mechanisms, through standards and regulations on new generation plants, new buildings, end-use appliances, vehicles, etc. Some of those measures, like upgrading building codes, would have both short and longer-term efficiency impacts.

Mid-term measures to reduce emissions would add to short-term ones, and focus on periodically reviewed and tightened standards, but also on switching to less carbon-intensive fuels, improvement of existing technologies through a mix of government-industry partnerships in R&D and regulation. Mid-term measures having longer-term impacts would include building infrastructure for mass transit systems, inter-modality, modification of urban planning rules, or simply improving the electricity, gas and oil transport and distribution infrastructure.

Both short-run and mid-term measures would see a substantial participation of businesses and consumer organisations to ensure that the markets work efficiently to provide goods and services that meet the desired environmental performance and quality standards.

Longer-term measures would add to efforts in the short and medium run an aggressive approach on the technology side, boosting long-term research and development efforts in the direction of substantially reduced or zero-GHG emission technologies. This technology push would begin by 2005 and continue throughout the scenario period, but would only begin to yield significant results and new technologies that can successfully be introduced into the market after 2020. Basic research would allow the development of a large pool of promising options, some of which would include enabling technologies that vastly improve the performance of an existing technology, while others would represent entirely new technologies. Government spending in basic research and development of new and improved technologies would increase and partnerships with industry would be sought throughout the process.

Besides a more widespread adoption by consumers of more parsimonious consumption patterns with respect to energy products/services, preference for products that use less material and energy (both in manufacturing and

operating) would induce businesses to produce increasingly more efficient vehicles, appliances, homes and so on at affordable prices. Businesses' environmental credentials would be continuously scrutinised by consumers and by pro-environmental interest groups. Consumers would favour energy products/services that do not generate (or generate fewer) GHG emissions over GHG-intensive ones, even at somewhat higher prices, thus further stimulating the market for these.

The mix of fuels in power generation would gradually shift towards fuels with a lower or zero carbon content (away from coal and towards more gas and more renewables). However, fossil fuel resources (in particular coal and gas) would still continue to be used for power generation. While their use would have significantly improved in terms of efficiency, CO_2 emissions from the power sector would still be increasing at the global level. New generating capacity would favour technologies with higher conversion efficiencies, especially for thermal plants. Decentralised power production would allow a decrease in transmission losses.

In this framework, carbon separation and sequestration technologies would receive increasing attention. Carbon sequestration could take advantage of improvement in geological surveying and exploration technologies developed in the oil and gas industry and start to be utilised on an increasing scale; this would apply particularly to re-injection in exhausted hydrocarbon-bearing formations. Efforts to find new more cost effective approaches to carbon separation would be steeped up.

Nuclear, in the initial stages of this scenario, is not seen as a priority due to the other environmental risks it presents, but is maintained in the picture for its carbon emission-reduction potential. Later on, reactor safety, long-term secure and safe storage of spent fuel and irradiated material would become the main focus of nuclear research. New and safer reactor concepts would be explored; in particular reactors that produce less radioactive waste and that reduce the likelihood of catastrophic accidents. Sites and technologies for long-term disposal would be further studied.

In the industrial sector, natural gas would be the favourite fuel for heat production. Technologies that use industrial waste as fuel or that recovery waste-heat would be increasingly employed. CHP production would increase significantly. Electricity demand, although moderated by significant increases in the efficiency of both industrial and household electric appliances, would keep growing.

In the residential sector CHP would be more broadly used, as well as solar systems integrated into buildings for water heating or for power production. More efficient heat pumps would be used for space conditioning in buildings, but passive heating and cooling systems and architectures would also be developed. Building management systems, using ICT to monitor and control the energy needs of entire buildings would become increasingly common.

In the transport sector, part of the mobility needs at urban level would be increasingly covered by car-pooling and by car-sharing systems, allowing people to use a car when needed, paying for that limited service plus some membership fees, but without actually owning the vehicle. In cities the number of street lanes dedicated to public vehicles and bicycles would increase and more people would choose to walk or ride a bike to work. In many cities the trend towards increased urban sprawl would start to be reversed, and city planning would encourage more compact city development patterns. Mass transit systems would serve growing shares of the urban population. The combined effect of these choices would be to decrease car traffic congestion and to increase the overall energy efficiency of the transport system, on top of the improvements in the fuel efficiency of vehicles. The latter would increase significantly, owing to concerted efforts in this direction from automakers, fuel producers, governments and consumers. New vehicles, through various combinations of electric and combustion engines and of fuel cells would reach much higher efficiencies. In freight transport, the trend towards an increase in road transport would be stopped and then reversed by increased investment in rail systems and port facilities allowing the movement of more goods by rail or ship as well as the speed-up of loading/unloading of goods. A more efficient organisation of trucking services would allow greater energy efficiency in this sector too. As a result, emissions from the transport sector would start edging down even at increased activity levels.

By 2020 the cumulative effect of these efforts would lead to a decrease not only of GHG emissions from the energy sector but also of total primary energy demand. They would have the simultaneous benefit of reducing supply security concerns, particularly with respect to oil. However, gas demand would grow, at least in the near term.

Institutionally, the Kyoto process continues, initially without the US, which focuses on a more aggressive technology and R&D effort. Parties to the Protocol take short- and mid-term measures sufficient to meet the Kyoto goals for 2010. A progressive willingness of developing countries to act, as

well as indications that technology can be successfully harnessed to keep prices down, leads to the negotiation of subsequent international accords to further reduce emissions.

Developing Countries

Gradually, developing countries would agree to become involved in the process. Initial incentives grow from the Kyoto Protocol's Clean Development Mechanism, which proves a somewhat cumbersome but increasingly effective tool to promote the sale by developing countries of certified emission reduction credits from both their energy and the agriculture/forestry sectors. Due to the relatively lower cost of emission reductions in developing countries, important flows of investment in state-of-the-art energy technology and infrastructure would be directed towards these countries. In addition, economic growth in the developing world is coupled to an increased appreciation for the environment, and growing demands from citizens for its protection. The initial focus would be on local environmental conditions, often to mitigate increasing health problems, but later the interest would be increasingly global in scope. Finally, developed countries continue to push this attitude both diplomatically, and through increasing use of aid that promotes a climate-friendly development path.

Over time, old and inefficient power plants would be replaced with very efficient ones, or green-field plants would be built with the best-proven technology. New gas turbines and gas combined cycle plants would be installed. And where only coal is available, supercritical thermal plants, with efficiencies above 44%, would be built, subsequently followed by advanced clean coal technologies such as coal gasification and combined cycles or pressurised-fluidised bed combustion. Hydroelectric dams and wind farms would also be built, often with help from foreign financing institutions. Small energy projects would target rural needs for electricity with renewable technology applications (wind, solar PV, biomass-fuelled generation). International funding would not be used for new nuclear power projects, although projects of refurbishment and upgrading (for safety purposes) of older plants would continue, especially in the former Soviet Republics. But new nuclear plants would be certainly built by fast growing countries to meet increasing power demand.

Demand for gas in power generation would increase dramatically, and prices would rise. The expanding market for gas would attract domestic and international capital for investment in gas pipeline construction, by then a booming industry. Demand for oil would also increase rapidly,

driven by the growth in incomes and in transport service demand, but it would do so at a somewhat slower pace than in the Dynamic but Careless scenario.

Combined international financing and domestic resources would be used for the construction and operation of mass transit systems in the sprawling mega-cities of the developing world, as well as for railroad construction and forest conservation projects.

The new markets created for more efficient and cleaner energy technologies would accelerate technology improvement and learning, creating global spillovers. New technologies would mature faster in an expanded market that now includes both developed countries and developing ones. In the latter, technical skills and engineering know-how will grow, amplifying the capability of absorbing new technologies and then to adapt and improve them. This will strengthen a virtuous cycle of faster technological progress that will also build on increasing income and education levels of the population in developing countries.

In a world of open markets, values, behaviours and products that have become fashionable in environmentally conscious developed societies would spread first to the wealthy and educated elites of the developing countries, and then reach the middle classes. Consumer durables with improved environmental standards and performances would spread world-wide following the same route, and increasingly stringent product standards would be rapidly adopted by developing country manufacturers, especially as they want to tap the markets of the rich world.

Energy demand, and GHG emissions, in developing countries would continue to increase as their economies grow and go through more or less accelerated industrialisation (some of the small ones may skip a heavy industrial stage, to move directly to a services/tourism economy). However, through extensive use of various forms of carbon trading and CDM mechanisms, emissions would grow much less rapidly.

2025-2050: Joining Efforts for Long-term Technology

With few notable exceptions, the leadership in science and technology will remain in developed countries for the first 20-30 years of this scenario horizon. Thus, by 2020 these countries would be still leading the effort to reduce GHG emissions and likely be the only ones taking increasingly stringent GHG reduction commitments. The responsibility to develop technologies with very low or zero GHG emissions still rests on their shoulders.

Increasingly aware of the task at hand, governments of developed countries launch a broad collaboration effort and join forces for technology development: the goal is to provide humankind with a set of technology options for carbon-emission-free energy production. This would be done through international partnerships between public and private research institutions working both around tried and tested technologies with significant perspectives to contribute towards the goal, or around a series of new technology concepts that have emerged in the laboratory.

Desirable technologies would be of two basic types:

- technologies for electricity production having very low or zero carbon emissions; and
- technologies for transport and mobility having very low or zero carbon emissions.

Technologies for power production are extremely important due to the increasing role electricity is expected to play an in the society of the future (at least for the next 100 years). In fact it is highly likely that besides providing for lighting and powering machines and computers, electricity use will continue to expand in the transport sector. In a world that wants to break free of GHG-emitting vehicles, electricity will either be stored in batteries or produced on board vehicles. The two alternatives could roughly correspond to electric vehicles powered by batteries or to fuel cell vehicles powered by hydrogen. Hydrogen could even be an intermediate storage medium for power.

Growing resources would be devoted to this planetary scale endeavour and a variety of directions of research would be pursued.

Zero GHG emission technologies for power production at the outset would be largely concentrated on nuclear power and renewables: research and development in both areas would be continued, although focusing on entirely different types of problem.

Over the previous 25 years research on reactor safety, safe storage of spent fuel and irradiated material and new and safer reactor concepts would have produced their fruits: new reactor designs producing less radioactive waste and less likely to originate catastrophic accidents. Sites for long-term disposal would have been found. In the meantime, although slow, construction of new nuclear plants would not have stopped in OECD countries (as it would not in some developing ones).

Over the first 20 years of the scenario, renewable energy use would have grown, and prices dropped, making them increasingly competitive, partly thanks to policies that favour them in terms of fiscal advantages. Wind technologies would have become cheaper thanks to economies of scale, manufacturing volume, better materials and R&D advancement. Solar PV technologies would also have become cheaper thanks to improvement in thin-films technology, improved conversion efficiencies, and better integration in building architecture. Improvements in technologies for power-grid management would also have contributed to their increased success. High temperature solar-thermal applications for electricity generation would have evolved to reach fairly high conversion efficiencies and competitive economics. They would be ready for larger scale adoption. Power storage technologies would also have improved. On the other hand, technologies for biomass energy production (direct heat, electricity or liquid and gaseous fuels) would also have improved, and become competitive. However more aggressive deployment tactics and continued R&D will stimulate production of power on a scale comparable to that of conventional thermal plants.

As a longer-term option, electricity from fusion reactor technology would still be pursued, with progress in special materials suggesting that it could become commercial after the end of the scenario period.

Carbon separation and sequestration technologies would be already competitive and ready to be utilised on a large scale. Sequestration in deep aquifers will be pursued further and the technology improved. Combinations of these two technologies later would open up perspectives for large-scale hydrogen production from fossil fuels like oil and gas. They would also have a role in hydrogen production from coal gasification.

Hydrogen itself would also be produced by electrolysis from off-peak electricity generated in nuclear plants. But electrolytic hydrogen could also be produced from renewables (solar PV, solar thermal, and wind) when cheaper solutions are not readily available. In a fast technological development world, other ways to produce hydrogen, using biological agents (microbes) might also be developed. Hydrogen could be produced close to consumption points, which – particularly important in the early stages of a transition toward hydrogen – would limit the need for long-distance distribution networks. This would allow for a faster penetration in some niche applications (for instance to produce power in stationary fuel cells, both for small size applications of apartment or building size, or for larger scale

production), without the need for large pipeline infrastructure to be developed right away. That, however, may well become necessary later.

Technologies for transport that do not emit GHG would be very important too. By 2020 vehicles powered by carbon-based fuels will have increased their efficiency significantly, thus decreasing CO_2 emissions per unit of service delivered. But to allow continued development, a zero-carbon technology will be needed. The energy vector is most likely to be electricity. The uncertainty pivots on the question of whether electricity will be supplied by a battery or produced on board in a fuel cell powered by hydrogen.

For purely electric vehicles research work on electricity storage in on-board batteries would be necessary to increase the energy density of battery packs, so as to give electric vehicles an operative range comparable at least to that of present day gasoline cars. But this type of solution might prove to be very difficult, requiring some form of on-board generation of electricity.

The fuel cell technology, especially for mobile applications, would have developed faster after 2010, as a way to improve energy efficiency, but still using carbon-based fuels. Now that GHG emissions become a serious concern, the technology could be used with hydrogen as a fuel. As mentioned, in this case it could work as a form of energy storage and in fact be a form of power storage. However, efficient ways to concentrate it, to increase its energy density, and to store it for fairly long periods (days or months) would be needed, especially for mobile applications.

As a result of large international research efforts, it is likely that significant breakthroughs in one or more of these technologies would be made before the end of the scenario horizon considered, thus providing a long-term answer to the problem of climate change mitigation without significantly restricting economic growth and the satisfaction of future demand for energy services.

Development on a large scale of the options illustrated above could lead first to further reductions in GHG emissions in developed countries and then to a significant slowdown and reduction of developing countries emissions by the end of the period. Diffusion of these technologies in developing countries may follow similar patterns to the ones seen for more conventional technologies. However by 2050 in this scenario many more countries will have joined the club of industrialised countries, thus making advanced technologies more affordable to a larger share of the world population.

Comments and Implications of the Three Exploratory Scenarios

General Comments

The three scenarios outlined in this chapter represent three rather extreme views of the future. This approach was taken on purpose, to cover a wide range of cases concerning the chosen variables and as a way to clarify logical chains of events and possible consequences. To some extent, all three scenarios have elements of plausibility. Thus, talking about the "likelihood" of any particular scenario is not appropriate. In fact, it seems likely that the future world will be some combination of the three cases – and perhaps other stronger drivers will emerge over time that will pull the future in entirely different directions. But from our specific point of observation (defined by time and by the specific mission of IEA), this exercise allows us to think about the future in a more systematic way, to identify potential threats and opportunities lying ahead.

Due to the way exploratory scenarios are usually built (i.e. by assuming that a certain driver, for example, attitudes towards the global environment, maintains the same thrust without changing direction over a long period of time), the realism of the story they tell may be limited, at times severely. In reality, of course, some of these drivers may show varying intensities and directions over time. Yet scenario construction demands that they remain steady over the scenario horizon and that a number of other factors develop over time consistently with the direction of the chosen drivers. While it is clear that complex systems like the ones that form the object of our investigation are not always consistent, scenario consistency is extremely important because it allows the following of a logical chain of effects and their explicit examination, providing useful insights for the planning stage. Clearly, in the scenario process there is an inescapable element of oversimplification that must be kept in mind. However, such simplifications need not detract from the utility of the analysis.

Along similar lines a few other remarks are important. The type of information about causal links and feedbacks among factors in a system like the one considered that is often represented in a modelling framework, is also embedded in the groundwork for scenario construction. In general scenarios do not contradict undisputed knowledge about social and economic systems. However, storyline scenarios are able to take into account and capture additional elements of these systems: two-way causal

links and feedbacks whose existence may be "guessed" by researchers but not fully proven by empirical analysis; irrational elements in human and social behaviour that are often not recognised by standard economic theory; value systems that influence human choice and behaviour in an often unpredictable way. These elements must be woven into a scenario in such a way as to make more compelling a plausible and convincing story, like additional strokes of colour in a sketchy picture.

But it is important to remember that not all elements in a scenario need to be entirely accounted for: some of them can be arbitrary and ultimately decided by the scenario-builder simply because there is no recognised rule stating that a certain combination of factors should always produce a given result. Consider the impact of increasing incomes on consumption of certain goods like apartment size in scenario 2 and 3. Both scenarios are characterised by fairly high income, which should lead to increasing size of houses, but while in scenario 2 this is the case, in scenario 3 people's preferences go to somewhat more compact houses and cities. What causes the difference? The influence of environmental values? Policy intervention? This type of question often puzzles the reader of a scenario, but the answer remains open.

These scenarios represent only an initial basis for discussion on possible future worlds. To complete this thinking exercise and extract from it a maximum of insight is also necessary to:

- examine the implications of the various scenarios, for instance with respect to the goals of the scenario developer. In this case, they can be assessed against the shared goals of the IEA (Energy security, economic development, environmental sustainability), or with respect to other criteria such as access to energy (as a part of the definition of sustainability and security), and speed of transition to a more sustainable world (with respect to the climate threat);

- examine the broad technology implications of the three cases considered and identify the technologies that appear most robust across scenarios. This could help identify a list of priority technologies to be further developed.

Implications for Policy and for Technology

Concerning the first point, two of the scenarios illustrated in this chapter present some obviously undesirable traits.

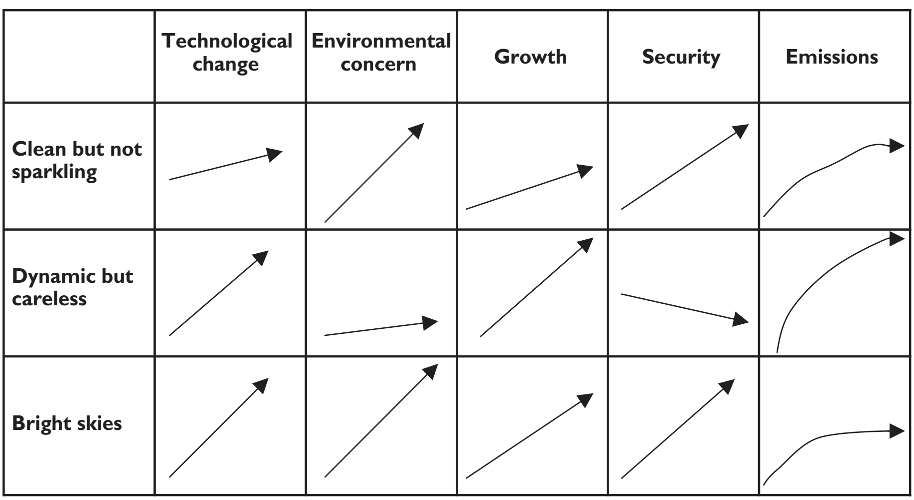
Scenario 1 (*Clean but not Sparkling*), while taking as its starting point a significant increase in the currently prevailing attitude of concern towards the environment, ultimately fails the goal of creating the conditions for long-term sustainability, as technologies that allow the system to decarbonise fast enough without sacrificing economic growth are not developed.

Scenario 2 (*Dynamic but Careless*) initially poses no environmentally driven constraint on economic growth, but by increasing demand pressure on scarce fossil resources, poses substantial risks from the point of view of global security. Furthermore, through acceleration of GHG emission rates, it threatens some of the environmental resources on which economic growth of future generations depends. However, this is a scenario that goes a long way towards widening the technology options for a more sustainable future later on.

The third scenario (*Bright skies*) is the most favourable from the point of view of meeting the conditions for long-term sustainability, and presents the lowest risks of the three scenarios from the point of view of security of supply and environmental protection.

Figure 2.5 summarises in a qualitative fashion the main characteristics of the three exploratory scenarios developed.

Figure 2.5 Three Exploratory Scenarios: Qualitative Directions of Change



All three scenarios indicate for the coming fifty years a substantial growth of gas demand worldwide: the reason is a shift to a less carbon-intensive fuel mix in scenario 1, diversification and economic considerations for

scenario 2 and both environmental and economic reasons for scenario 3. In all these scenarios gas would be overtaking coal and then oil at some point during that period. In consideration of such growth in demand, gas prices would increase unless exploration, extraction and transport costs decrease fast enough over time. This suggests that finding gas in the quantities needed and then delivering it to the consumption markets is going to be a daunting task for the coming decades. Oil demand would also increase, although not as fast as gas demand, and not at the same pace in the three scenarios considered. Even leaving aside the effects of resource depletion, geopolitical risks associated with the location of known oil deposits are likely to provoke recurring crises in the oil markets and price spikes.

These scenarios (and particularly the second, *Dynamic but careless*) remind us that in worlds heavily reliant on oil and gas resources, problems arising from the actual spatial distribution of these resources have the potential to disrupt energy markets even when amounts available in the ground are adequate, and technologies to extract them exist.

All three scenarios assume that developing countries will continue to develop over the coming fifty years, although at different speeds both across scenarios and across countries. In scenario 1 and 3 this would lead to a certain measure of convergence of per capita incomes between OECD and developing countries, while income gaps could actually been maintained in scenario 2, where some particularly unfortunate areas fail to catch-up. Continuing development in non-OECD countries would lead over the period to energy consumption forms and patterns that are increasingly similar to those of the developed societies, although at different absolute levels. The idea of non-commercial energy sources would disappear more or less rapidly depending on the scenario and increasing shares of the world population would have access to electricity. This however is a somewhat optimistic choice on our part: in fact, the case of diverging income trends and rapidly increasing inequality cannot be ruled out of the picture.

The three stories indicate that for long-term sustainability it is critical to ensure robust dynamics in technological improvement but that unless there is a fundamental change in values and attitudes towards the global environment, technology alone cannot be trusted to find the right solutions. Supposedly values and attitudes are what give direction to technological change and, vice versa, the direction of technological change reflects the system of values of a society.

Also, these scenarios show that policy can have a role not only in directing research and technology development towards the attainment of specific social objectives but also in favouring (or hampering) successful and rapid technological change.

However, while designing intelligent policies that increase the chances of successful technological development is something that can be done by good policy analysts, implementing the policies requires political will, and that ultimately depends on social values and priorities: an altogether much more difficult variable to change.

Concerning technology implications, the three scenarios present clear differences with respect to the technologies that are more likely to emerge in each of the three different contexts:

- Scenario 1, besides stressing spartan behaviour on the part of energy users, concentrates on more energy efficient and cleaner end-use technologies, on fuel switching and on renewable energy technologies. It later reconsiders zero carbon-emitting technologies like nuclear;
- Scenario 2 focuses initially on fossil fuel-based technologies but later, in order to mitigate security of supply concerns develops other alternatives, like nuclear and hydrogen;
- Scenario 3 develops the entire range of options, choosing both near term focus on efficiency and a longer-term focus on zero-carbon-emitting technologies for medium to large-scale energy production.

A more detailed look at the technology aspects of these story-lines allows some additional insights to be drawn from our scenario exercise, particularly in view of the consideration of security of energy supply and environmental sustainability. Table 2.1 (page 106) summarises the list of main technologies emerging from each of the three scenarios, broken down by sub-period (2003-2025 and 2025-2050) and by energy sector (supply and demand).

Table 2.1. Emerging Technologies from 2003 to 2050 in Three Exploratory Scenarios

Time horizon and sector	Clean but not sparkling	Dynamic but careless	Bright skies
2003-2025			
Energy supply	Energy efficiency improvement (EEI) technologies. Gas turbine plants replace coal fired plants in OECD; Cleaner coal fired plants in many DCs (pulverised coal, FBCC, PC supercritical and PFBC later). Gas-fuelled generation in various forms. Gas transport technology Combined cycle gas turbines, first in OECD and later DCs. Pollutant abatement technologies (SO_X, NOx, PM) CHP Micro-generation (gas) Stationary fuel cells Few new nuclear plants; life extension and safety in OECD. Power generation from renewable sources: Solar PV, Wind, Biomass Hydro (mostly in DCs) Continued R&D on fusion	Oil and gas exploration, extraction and transport technologies. Oil shales and tar sands treatment technologies. New power generation fuelled by coal and gas: centralised options Some decentralised power in OECD Pollutant abatement technologies (SO_X, NO_X, PM) Large hydro projects in DCs. Wind power, where competitive. Nuclear programmes restart in 2015-2020 in DCs and some OECD countries. Gas transport technology gas liquefaction and regasification technology. Coal liquefaction and gasification technologies. EEI technologies for energy transformation important towards end of period	Rapid energy efficiency improvement (EEI) in supply technologies. Low carbon fuels (gas and renewables) in power generation Combined cycle gas turbines first in OECD and later in DCs Gas transport technology. Gas liquefaction and re-gasification technology. Cleaner coal in coal-rich DCs (Pulverised coal, FBCC, PC supercritical and PFBC). Pollutant abatement technologies (SO_X, NO_X, PM). CHP Micro-generation (gas) Stationary fuel cells Few new nuclear plants; life extension and safety in OECD; new reactor concepts explored. Power generation from renewable sources: Solar PV, Wind Biomass, Hydro (in DCs) Continued R&D on fusion
Energy demand	EEI and conservation in all demand sectors; More efficient appliances; Fuel efficiency improvement in gasoline and diesel vehicles. Hybrid vehicles and fuel cells (gas-fuelled) in OECD. Both in OECD and DCs: Bio fuels; LPG and methane; Mass transit systems; Improved city planning. Fuel efficiency improvement (FEI) in aircraft	In OECD greater penetration of gas and electricity in industry and residential. Electricity-intensive lifestyles. Coal remains important in industrial end use in DCs. Transport sector relies heavily on oil. Bigger and more powerful cars. Hybrid vehicles and fuel cells (gas fuelled) cars for transport in OECD. EEI becomes important towards end of period in all demand sectors	EEI and conservation in all demand sectors. More efficient appliances. Less energy- and material-intensive manufacturing processes and services. Passive heating and cooling technologies & architectures in buildings. Building management systems. FEI in conventional vehicles. Hybrid vehicles and fuel cell (gas-fuelled) cars in OECD, later in DCs too. Both in OECD and DCs: Bio fuels; LPG and methane; Mass transit systems; inter-modality, improved city planning. EEI in aircraft

Time horizon and sector	Clean but not sparkling	Dynamic but careless	Bright skies
2025-2050			
Energy supply	Continued EEI as in the previous period. Improvement in renewable energy technologies. Continued focus on gas. Resumption of nuclear programmes especially in DCs Carbon capture and storage Continued R&D on fusion	Large-scale resumption of nuclear programmes Hydrogen production technologies (from gas, coal nuclear or biological agents). Fuel cell power plants Carbon capture and storage Continued R&D on fusion Technologies for hydrogen transport and long term storage Some carbon capture and storage technologies Wind power Solar thermal develops Fusion gets closer to commercial stage	Large-scale resumption of nuclear programmes. Significant share of new renewables in power generation (wind, PV, high temperature solar thermal, some biomass) Hydrogen production technologies (from gas, nuclear or biological agents). R&D on power storage technologies Fuel cell power plants Carbon capture and storage ready for large-scale use. Technologies for hydrogen transport and long term storage Fusion gets closer to commercial stage
Energy demand	Continued EEI and conservation in all demand sectors; More efficient appliances; Greater penetration of gas and electricity in industry and residential. Super-diesels, hybrid vehicles and fuel cells (hydrogen fuelled) in transport. Both in OECD and DCs: Bio fuels. Public transport systems. New city planning.	Continued EEI and conservation in all demand sectors in conjunction with wider use of ICT Fuel cell vehicles in transport Micro-generation for direct use of power	Continued EEI and conservation in all demand sectors in conjunction with wider use of ICT Hydrogen fuel cell and electric vehicles in transport. Hydrogen storage technologies. Bio fuels in OECD and DCs. Public transport systems. New city planning. Fuel cells for direct use of power

Table 2.1 helps isolate the technology areas that are common to all three scenarios. These areas may thus be ripe for policy development. On the energy supply side these include:

- energy efficiency improvement (EEI) in supply technologies;
- advanced gas technologies in power generation: combined cycle gas turbines;

- gas transport, storage and liquefaction/re-gasification technologies;
- cleaner coal technologies (Pulverised coal, FBCC, PC supercritical and PFBC);
- CHP;
- micro-generation (gas);
- technologies for criteria pollutant abatement (SO_x, NO_x, PM);
- stationary fuel cells;
- nuclear technologies; life extension and safety; new reactor concepts;
- power generation from renewable sources: solar PV, solar thermal (including high temperature); wind; biomass; hydro-power;
- hydrogen production technologies (from coal, gas, nuclear or biological agents);
- technologies for hydrogen transport and long-term storage;
- power storage technologies;
- fuel cell power plants;
- carbon capture and storage for large-scale use;
- fusion.

On the energy demand side they include:

- energy efficiency improvement and conservation in all demand sectors: more efficient appliances, wider use of ICT to optimise performance;
- fewer energy- and material-intensive manufacturing processes and services;
- passive heating and cooling technologies and architectures in buildings; Building management systems;
- fuel efficiency improvement in conventional vehicles;
- bio fuels;
- LPG and methane;
- hybrid vehicles;

- fuel cell (gas- or hydrogen-fuelled) cars;
- hydrogen storage technologies;
- electric vehicles;
- mass transit systems;
- advanced public transport systems;
- fuel cells for direct use of power.

Development and diffusion of these technologies can contribute either to overall improvement in the efficiency of energy production and use or to reduction of GHG emissions, or to both. In some cases, they could also help mitigate security of supply risks. On this basis their development at acceptable costs would be desirable.

Some technologies however appear mainly in the Dynamic but careless scenario. These are:

- oil and gas, extraction and transport technologies;
- oil shales and tar sands treatment technologies;
- enhanced oil recovery technologies;
- coal liquefaction and gasification technologies.

The reason for their appearance only in that scenario is that this scenario has a strong focus on fossil fuels and limited interest in reducing CO_2 emissions. While this second group of technologies would be helpful in reducing security of supply risks (and that is especially true for coal-based ones), greenhouse gases would be produced in massive amounts should some of them (like coal liquefaction and gasification) become very competitive and widely used.

These are only initial considerations on issues of technology development. They will be developed further in the more policy-oriented context of the next chapter.

A NORMATIVE SCENARIO TO 2050: THE SD VISION SCENARIO

Background

The scenarios proposed in the previous chapter were built for the purpose of exploring a range of outcomes and analysing their implications for strategic decision-making. This chapter presents an example of a global "normative" scenario to 2050, the SD Vision scenario (where SD stands for "Sustainable Development").

In "normative" scenarios the perspective is different from that of exploratory scenarios: a normative scenario outlines a "desirable" vision of the future or a goal into the future. These goals can be expressed by specific metrics or quantitative targets to be reached by the end of the time horizon considered. They are, in turn, used as a point of departure to identify the conditions that must be fulfilled or the measures to be taken at different stages along the path to implement that goal or vision. Typically, normative scenarios tend to work in a "back-casting mode". While "exploratory" scenarios set the groundwork to describe *what could happen*, "normative" scenarios help *decide what could or should be done in order to achieve the set targets*, and hence are more concerned with action. In practise, normative scenarios of this type are rarely found in isolation, i.e. without previous analysis, done with the help of exploratory scenarios, of what the future might bring (De Jouvenel, 2000; Greeuw et al., 2000).

Readers may not share the vision of the future outlined by this "normative" scenario: neither necessarily do we. Rather, the purpose of the exercise is to illustrate the process of development of such scenarios and to stimulate discussion and thinking from different perspectives about a number of long-term issues that would emerge where energy and environment intersect.

Borrowing from a scenario developed at IIASA for the IPCC, a description and a broad quantitative framework for this SD Vision scenario to 2050 has also been constructed. Based on this structure, this chapter then proceeds to evaluate some of the policies and technology developments that would be needed to realise that future. The IIASA scenario was chosen

purely for illustrative purposes. While it contains elements reflective of ongoing work within the IEA, its use in this context is not, in any way, an endorsement of this future.

Normative Characteristics

To define this scenario's normative characteristics, three main areas are particularly relevant. These are:

- climate change mitigation;
- energy security and diversification; and
- energy access.

Within these three general objectives, specific characteristics need to be identified to represent the targets or "norms" to be met by the desired image of the future; these must then expressed in a parametric fashion.

The process of defining such targets, however, is complex. To build a robust scenario, targets for 2050 need to be able to stand the test of time, (i.e. they should not be dependent on contingent situations of today) and they should have clear measurable dimensions that help develop prescriptions for human action. The target development process is described in the following sections of this chapter.

Climate Change Mitigation

With respect to climate change, the main consideration used in the scenario development is that the global energy/economy system would find itself on a GHG emissions path that does not cause "dangerous anthropogenic interference with the climate system" (Article 2 of the United Nations Framework Convention on Climate Change - 1992). However, there is still considerable uncertainty as to what emission levels and rates constitute such "dangerous interference".

Some basic facts help constrain this element of the analysis. The climate system is controlled by a large number of factors, many of which are beyond human control. However, since the industrial era began, the increase of emissions connected to human use of fuels or of land has been progressing at an unprecedented pace. CO_2 and some other greenhouse gases are long-lived, i.e. tend to stay for a long time in the atmosphere. When the rate of emission of CO_2 is significantly higher than the rate at which it is absorbed

by the ecosystem, as is the case presently, emissions concentrations increase. This increase, in turn, leads to temperature changes.

In practice we are unable to pinpoint with satisfactory accuracy the extent of possible damage stemming from any specific increase in average temperatures. Furthermore, inertia in the climate system is such that the change in temperature will take place only gradually and reach a new equilibrium level only over hundreds of years. By the time this change occurs, it will be too late to act to avoid it. The equilibrium temperature change over the next 100 years has been estimated by the IPCC (2001a) to lie between 1.4°C and 5.8°C.

Uncertainties make it difficult to estimate the risk. However, we know that human activities lead to emissions at a rate substantially higher than the global ecosystem can absorb. If we want to stabilise emissions at any level, we need ultimately to reach a point in which net emissions are close to zero. To get to that point, we will first need to reverse the current trend of rapidly increasing emissions, especially those stemming from the energy sector, currently of about 22.6 billion tons per year (if we only consider CO_2, as done in the IEA World Energy Outlook 2002) and increasing at about 1.1% per year.

The IPCC third Assessment Report computed distinct emissions trajectories compatible with different stabilisation levels of emissions concentration. These trajectories have themselves a significant range of variation. If for instance we assume a target of 550 parts per million volume (ppmv) for emissions stabilisation by the end of this century, then cumulative carbon emissions over the 21st century cannot exceed 4033 $GtCO_2$ (in an optimistic estimate) and global emissions should peak between 2020 and 2030 and start decreasing afterwards. In fact, global emissions would need to fall below 1990 levels before 2100, and perhaps as early as 2030 (see IPCC TAR Synthesis Report, Table 6.1). If the goal is more ambitious (450 ppmv stabilisation) we need to limit cumulative carbon emissions over this century to between 1340 and 2680 $GtCO_2$ and start reducing emissions between 2005 and 2015. Less stringent emissions stabilisation targets than 550 ppmv would provide more time for adjustment – but carry larger risks in terms of climate impacts.

Although we know that at some point we will have to reduce global emissions, the uncertainties that plague every stage of the climate change cycle make it difficult to gauge more specifically any mitigation strategy[1].

1. For more extensive discussions of the difficulty in identifying long-term targets, especially in the context of policy action, see J. Pershing and F. Tudela (2003) and C. Philibert et al. (2003).

Only the most aggressive emissions stabilisation strategies seem to be relatively "safe" (assuming there is consensus on the level of safety) but these carry fairly high economic costs in terms of foregone income growth, because they require an emissions reduction effort that with current technologies is difficult to achieve. On the other hand, less aggressive strategies risk simply shifting part of the burden (in terms of negative impacts of climate disruptions on societies in areas of health and natural amenities and the ability to create wealth) to future generations.

In developing this normative scenario exercise two alternative types of target were initially considered:

- an arbitrary global emissions reduction target with respect to 2000 levels (similar in structure to that proposed by the Kyoto Protocol); and
- a target focusing on decarbonising the energy supply (for this case, calling for a given share of zero carbon sources in total world primary energy supply, by the year 2050).

While the first target, if met, would ensure that global emissions would indeed be reduced, it has not been acceptable either to the US or Australia – nor to date, to any developing countries. The second alternative puts a strong accent on development of non carbon-emitting technology, which could be a vital precursor to a transition to a non-carbon-based economy, although not ensuring that emissions will be actually decreasing on a global level by 2050.

Thus, the second alternative was chosen for this exercise. The selected target calls for a 60% share of "zero carbon" sources in total world primary energy supply, by the year 2050. There is necessarily a high level of arbitrariness in adopting any precise number for such a long-term target. Earlier analysis (IEA, 2002a) shows, for instance, that the international community may not be in the position to adopt firmly a very long term GHG concentration target that should be reached at all costs. On the contrary, that analysis suggests that one should perhaps aim at "low" concentration levels but make full achievement of this aim conditional upon the level of real abatement costs - which cannot be known today. However, setting such an aim within this scenario provides a basis for assessment, and allows for an examination of the types and stringency of policies that would be required should such a target in fact be sought.

Strictly speaking the qualification of "zero carbon source" may only apply to energy produced from nuclear fission and renewable technologies (and

perhaps, later, to nuclear fusion). However in the discussion that follows, technologies of capture and storage of CO_2 are fully included, and considered to reduce emissions by an amount equal to the assumed storage of CO_2[2]. It is also important to note that, while carbon sequestration in agriculture and forestry sinks has been considered by climate negotiators as an acceptable way to mitigate emissions, this option is not discussed here and the analysis focuses on energy issues.

Energy Security and Diversification

The issue of energy security and diversification is a particularly thorny one. It has recently taken centre stage in the energy debate in coincidence with the recent war in Iraq and with the increasing threat of international terrorism. In this section, we discuss the issue in a longer-term perspective and try to define appropriate targets to address energy security over a 50-year horizon.

Energy security has many faces. In general, the idea of energy supply vulnerability is an objective condition that leaves a system exposed to the risk that needed quantities of energy inputs and services fail to reach the intermediate or final users.

Vulnerability is felt more often at a local and national level than at a global level: even in a much globalised world there have been very few cases in the past of a threat or an actual supply disruption that acts at the same time in all areas of the world. A number of threats have been encountered in recent history:

a) dependence on foreign energy sources;

b) dependence on sources that are gradually becoming depleted on a global basis (e.g. dependence on oil and gas);

c) dependence on geographic supply areas that are politically unstable (*e.g.* dependence on Middle eastern oil, risk of disruption in the production and shipment stage due to armed conflicts);

d) dependence on a single technology;

e) dependence on a limited numbers of delivery lines (one oil or gas pipeline);

2. While we are aware of the "energy penalty" that has to be paid to produce a given amount of final energy from fossil fuels with capture and storage of part of the CO_2, for simplicity of discussion and as in the SD Vision scenario we are mostly referring to primary energy supply, we will not explicitly quantify it.

f) market power of energy-exporting countries and its possible use as a political weapon;

g) market power of energy deliverers (e.g. truck drivers strikes in the case of gasoline and other liquid fuels delivery);

h) risk of market disruptions due to regulatory bottlenecks or mistakes (which may, inter alia, cause insufficient levels of investment in infrastructure).

Case a) is of little interest per se, especially if we postulate open global markets over the next 50 years. Case d) could be that of France's electric power sector, that depends for more than 70% on nuclear plants. A serious reactor accident (or, as we have seen recently, a long spell of exceptionally hot weather combined with a drought) could force closure of a large number of plants, causing severe power shortages and serious mid- to long-term impacts, not necessarily limited to the country level. Case e) may be a longer-term problem, particularly for gas (as oil can also be transported by truck or tanker): in particular, the focus of concern are uncertainties about the speed at which the infrastructure, needed to bring to market the large quantities of gas that will be demanded in the coming decades, will be built. Case f) is a situation oil consuming countries faced in the 1970s with respect to OPEC; it might become less important as OPEC recognises its long-term economic interests. Cases g) and h) represent mostly local problems with temporary impacts, but could cause costly shortages of energy. In sum, cases b) and c) are the most serious cases of vulnerability, because they have both long-term and global relevance, followed by cases d) and e), which have a shorter term and more local impact.

In the timeframe of climate change, the problem of dependence on energy sources that are exhaustible is perhaps most significant. Depletion for conventional oil is not contemplated as a serious threat for the coming thirty years. But we cannot rule out that this might occur within the next fifty years, should the growth rate of oil demand be high enough. Phasing in unconventional oil resources would give more time (as well as higher emission levels), though depletion could still happen within this century. A similar risk is also manifest for gas if present rates of extraction continue or increase. In the case of coal, on the other hand, several centuries of supply remain assuming present extraction patterns. Of course, the concept of reserves, as the concept of resource base (of which reserves are only a part) is a dynamic one, i.e. it changes over time and, specifically, depends on technology and knowledge stock, prices and other economic factors. It also depends on definitions (conventional oil, non-conventional oil, etc.).

The issue of when production will peak and how long resources will last ultimately depends not only on the effective resource stock but also on its recoverability and on the resource production rate (which in turn depends on population growth, economic activity level, prices and ultimately on technology). For conventional oil, most experts agree that at current production growth rates production peaking could happen relatively soon between 2010 and 2050 according to different authors (Campbell, 1998; DOE/EIA, 2000); the WEO (IEA, 2002b) reference demand projections stand in the middle and suggest it may not happen until after 2030. For gas, remaining conventional resources are more abundant and, even at current rates of production growth, production peaking should take place after 2050.

But complete exhaustion for both oil and gas may very well never take place. Past experience shows that in human history no "exhaustible resource" has yet been depleted although individual deposits have been largely depleted or abandoned. This is certainly true for minerals. Instead, it is most likely that the oil age will not come to an end because we will run out of oil, but rather because we will have lost interest in it as a source of energy long before. The same is likely to be true for gas. Technology plays an important role in finding new resources, in improving their efficiency of extraction, in improving their efficiency of use (which tends to make a resource last longer) and, most of all, by making possible long-term transitions to other resources.

Thus, for the longer-term scenarios considered here, the key elements of energy security will include both political and technological components.

In order to give some measure of energy security (or insecurity) we need to identify an indicator of dependence, vulnerability or of diversification and a target value for that parameter by 2050. The choice of such indicators, however, is narrow and any given alternative may be particularly limited when applied over a long-term horizon and at a global scale[3]. Here we discuss two: the Sterling Index and a composite index of world dependence on OPEC oil.

The Sterling diversity index was originally developed to describe the level of diversity in electricity generation systems. It is defined as

$$DIV = - \Sigma_i\, p_i \ln p_i$$

Where p_i represent the proportion of fuel type i in a generation portfolio[4].

3. See for a discussion of measures of oil dependence the paper by J. Kendell (1998).

4. IEA: *Towards a Sustainable Energy Future.* Paris, 2001. Pp. 90-98.

The index increases as the number of supply sources increases. This index can probably be applied to other sectors than power generation and to different geographic origins of the same fuel. However it makes no distinction between desirable and undesirable states of the world, particularly with respect to the cost of diversification.

The index of OPEC oil dependence applies to the global scale of the problem but represents the vulnerability of the system at a specific point in time. It is constructed as a composite index of three different parameters:

- share of OPEC in world oil demand;
- an index of OECD oil stock levels (including strategic stocks) at a given point in time;
- excess OPEC crude oil production capacity [5].

The latter two elements have opposite signs with respect to the first. These three elements are given percent weights and the resulting average is expressed on a scale 0 -100: the higher the value, the more vulnerable is the world system to oil supply disruptions.

One of the difficulties with this indicator is that it is a composite of different variables: any value of the indicator could be the result of very different values of its components and, even setting a target value for the indicator at some specific point(s) in time in the future, an infinite number of solutions are possible. Furthermore, the relevance of this indicator remains subject to the hypothesis that some key OPEC countries remain unstable and would be willing to use oil sales to consuming countries as political weapon. Should they operate on a purely commercial basis of revenue maximisation, the problem of security of supply would largely disappear and consumer countries would be left with the old problem of resource exhaustion.

For the reasons explained, in this text we have used neither of the two indicators illustrated and resorted instead to a much simpler criterion. The basis of our reasoning is the following. In the coming 50 years, the sector in the global economy that is going to be more seriously dependent on Middle Eastern oil is the transport sector. That alone, if it keeps growing at current rates, is capable of absorbing all the resources of conventional oil available until 2050. The trend concerning other uses of oil, particularly power generation and to a lesser extent heating, is toward a progressive

5. DOE/ *Energy Information Administration: International Energy Outlook 1994*. Washington D.C. July 1994, pages 21-22.

reduction. Therefore, in order to reduce the supply security risks with respect to oil, we will consider, in the context of the scenario development, using a limit of the oil share in transport demand at the year 2050.

Currently oil represents about 95% of total transport energy demand. A target of no more than 40% of transport demand being satisfied by oil products could be stringent though perhaps still achievable. Of course, as with the climate change goal described above, this is an arbitrary figure – and serves more as a tool to promote analysis than in any way defining an agreed IEA target.

Access to Energy

Access to energy is a powerful indicator of the level of development attained by a country's population. The World Bank World Development Indicators (2003) include, among many others, indicators of per capita energy production and use, energy efficiency, as well as electricity production and access to electricity. In developing countries, growth in commercial energy use is closely related to growth in the modern sector of the economy, in particular industry, motorised transport and urban areas.

Among commercial (i.e. traded) forms of energy, electricity maintains an especially important role, as its use is closely related both to economic development and to the industrial and service phase of that development. It is also strongly related to other aspects of human development in general (like the diffusion of education and health services).

According to the World Energy Outlook 2002 some 1.6 billion people (one-quarter of the world population) in the year 2000 had no access to electricity. So access to electricity is a fundamental concern for a large proportion of the world's population that do not have it and at the same time is a desirable social goal at the global level. Providing such access would help mitigate world poverty with its long list of dramatic consequences in terms of human misery, and foster global development and economic growth. We believe therefore that this goal has a rather easy appeal and is much less controversial than those previously specified. As to the specific target, we could somewhat arbitrarily set it as follows: **to give access to electricity by 2050 to at least 95% of the world's population.**

Such a specific target is stringent enough to show the desired direction of movement, which is universal access to electricity, while acknowledging the difficulty of providing universal access in full. After all in other sectors, such as education and literacy, similar goals have not been achieved at 100% even in many developed countries.

Building a Reference Framework

Once the targets are defined, however, there is still a very large combination of scenarios that can meet them. The problem is to outline a set of desirable characteristics that are mutually consistent, based on what we know about the relationships among factors and variables in a socio-economic system.

For framing and building a normative scenario, a quantitative reference is useful, in particular, figures for global and regional primary energy demand at the year 2050 and a breakdown of that demand by fuels (fuel mix) that meet certain requirements (the norms). This helps visualise the magnitude of the necessary changes in the energy system and to discuss some of the policies that would be necessary to meet the targets discussed earlier. In this sense the quantification serves a purely illustrative purpose.

As building such a reference framework is a time- and resource- intensive exercise, it was not undertaken for this analysis. Instead, it was possible to draw from the available literature – which provides a vast array of examples. This exercise uses the quantitative framework provided by the SRES A1 family of scenarios (IPCC, 2000) described in the box[6].

Box 3.1. IPCC Scenarios

In its most recent set of scenarios (released in the Special Report on Emissions Scenarios, IPCC 2000), the IPCC explored a series of "no climate policy" cases through the year 2100. The scenario's main drivers include demographic trends, social and economic development and the rate and direction of technological change; these in turn affect energy demand and land use – and consequently emissions of greenhouse gases into the atmosphere. All scenarios are characterised by growing per-capita incomes (with world GDP increasing 10 to 26–fold depending on the case); income differences across world regions are assumed to narrow in many of the scenarios described.

The IPCC scenarios are based on four families of storylines, each representing a combination of different demographic, social, economic, technological and

6. We are aware of the fact that the validity of some of the assumptions underlying the IPCC-SRES scenarios, and particularly the scenarios of the A1 family were recently challenged by I. Castles and D. Henderson. One of their main objections centred on the use of GDP data measured at Market Exchange Rates (MER) instead of Purchasing Power Parities (PPP). As the rebuttal written by Nakicenovic et al. and published in issue 2 of 2003 of *Energy and Environment* provides some reasonable answers to the issues raised, we stick to our choice of reference framework.

environmental developments (respectively A1, A2, B1 and B2). The "A" worlds are basically ones where economic and market factors predominate, while the "B" scenarios are worlds with more focus on environment. The "1" worlds are more global in outlook, while the "2" worlds are regionally focused. Based on these four families, the more than 40 quantified individual IPCC scenarios cover a wide range of uncertainties on future GHG emissions. The *A1 story line* and scenario family describes a world characterised by very rapid economic growth, a population trend that peaks around 2050 and declines afterwards, very rapid introduction of new and more efficient technologies through high rates of investment and innovation and international mobility of people, ideas and technology. Other relevant characteristics are a continuation of globalisation trends; commitment to market-based solutions and increasing convergence of development among world region, leading to greater interregional equity in income distribution. Within the A1 family three scenario groups are identified, characterising three different developments of energy technologies. The first (A1FI) is characterised by emphasis on fossil fuel technologies, leading to worsened environmental conditions especially with respect to GHG emissions and climate change risk. The second (A1T) is characterised by development of non-fossil fuel technologies leading to a marked improvement of environmental conditions (including a reduction of GHG emissions). The third (A1B) is characterised by a fuel/technology mix that is more balanced across the fossil/non-fossil spectrum, due to uniform improvement rates across technologies, and results in a moderate improvement of environmental conditions.

For comparative purposes the main characteristics of the six marker scenarios of IPCC are shown in Table A.II.1 of the Appendix II.

Population growth assumptions in the A1 scenarios are consistent with the (newly released) revised population projections of the United Nations to 2050 (*2002 Revision of the official United Nations population estimates and projections*). According to this source, total world population by 2050 will equal 8.9 billion, i.e. an increase of 2.6 billion from the current 6.3 billion.

According to the revised UN projections the population of the less developed regions would grow from 4.9 billion in 2000 to 7.7 billion, while the population of more developed regions would remain stable around the current level of 1.2 billion. Life expectancy at birth is assumed to rise from a world average of 65 years today to 74 years in 2050. Due to lower fertility rates population would be ageing faster than previously projected even in developing countries.

Globally, people aged > 60 will reach 1.9 billion by 2050 and 80% of them will live in developing regions, where they will represent about 19.7% of the population (a figure approximately equal to the current share of senior citizens in developed countries). International migration is expected to remain high over the entire period. The difference in world population projections between the UN estimates and the SRES A1 scenarios might well be explained with an even further decrease in fertility rates due to the impact of fast income growth in the SRES scenario. On the other hand, a situation of slightly declining population after 2050 as in the A1 scenario would not be inconsistent with the UN projections.

Income growth assumptions for this scenario family indicate a robust growth rate of 3.5% per year over the entire period. This assumption, while perhaps optimistic, is consistent with global trends over the last 30 years according to IMF data. Furthermore, it offers some scope for a substantial improvement both of world-wide per capita incomes and for a significant reduction of the income gap between developed and developing regions (as in fact postulated by this scenario). While this is not a specific requirement for the SD Vision scenario, it is certainly a desirable characteristic and is consistent with energy access criteria. It is clear, however, that, as a result of environmental and energy security targets imposed on the energy system in our scenario, this rate of GDP growth would be somewhat lowered.

Concerning energy supply, the main assumption in the A1 scenario family is that there are sufficient fossil energy resources to meet demand in the next 50 years. Rapid technical progress increases economically recoverable resources and increases efficiency (i.e. it reduces the resources needed to produce a given unit of output).

Within the IPCC A1 scenario family, two scenarios provide particular relevance for the framing of our analysis: the A1T case, in which rapid technological change plays in favour of non-fossil fuel energy technologies, and at the A1B case, in which rapid technological change has a balanced impact on both fossil and non fossil fuel technologies. Appendix II contains a discussion of the quantitative features of two specific A1B and A1T scenarios, quantified with IIASA's MESSAGE model, for the projection period 1990-2050[7]. Trends in those two scenarios are also compared to the IEA's WEO-2002 reference scenario (which, however, only runs to 2030).

7. As these specific scenarios were quantified using GDP projections on a PPP basis, the objections raised by Castles and Henderson do not arise.

The A1B and A1T scenario outlines provide an initial quantitative framework for population, income growth and energy demand projections, on which we impose our targets or norms. They represent, therefore, a suitable basis for our analysis because of their fast technology and economic dynamics, which can accommodate dramatic changes like the ones envisioned in our normative scenario. The A1T case, in particular, shares with our "Bright skies" scenario discussed in the previous chapter its assumptions of rapid technological change and attitudes towards the environment.

A Normative Case: the SD Vision Scenario

To quantify our SD Vision scenario, we have used as a starting point the A1T scenario developed by IIASA with the MESSAGE model and available in electronic form in the Internet SRES-CIESIN website[8]. The basic data for the A1T MESSAGE scenario divides the world into four regions:

- OECD90 (which includes Western Europe, North America and Pacific);
- REF – Russia, Eastern Europe and former Soviet Republics;
- ASIA (including Centrally Planned Economies of Asia, Southern Asia and Pacific Asia);
- ALM (Middle East, Africa and Latin America).

We have maintained the basic structure of the original model results, however, the original storyline has been modified. For example, while the SRES scenarios are not policy driven, our SD Vision scenario requires strong policy intervention. Thus, the SD Vision scenario outlined here imposes a more stringent requirement regarding the share of zero carbon emitting sources, slightly lowering the economic growth trend and energy demand trajectory to fit the outlook of a policy driven scenario.

The assumption of this SD Vision scenario is that there is a strong political will to achieve the targets, that the general public supports or is persuaded to support those goals, and that businesses are willing to work toward that goal both with policymakers and with consumers. Such support is found both in the developed and developing world – the latter responding partly as a result of increasing incomes. However, achieving these goals has some

8. http://sres.ciesin.org/final_data.html. Some additional detail was provided by IIASA and we warmly acknowledge the assistance provided Dr. Nakicenovic and Dr. Riahi. We would like to make clear, however, that the responsibility for any mistakes or misuse of these data in this paper is entirely ours and does not extend to the modellers of IIASA.

cost in terms of economic growth – and although such costs are in part offset by other environmental benefits, a slight decrease of the growth trajectory may result from climate change mitigation efforts.

How slight is this decrease likely to be? An assessment of economy-wide impacts of CO_2 stabilization at various levels was carried out by the IPCC (2001b, p. 548) with the use of six different models (AIM, ASF, MARIA, MiniCAM, MESSAGE and World SCAN) by applying various mitigation policies and measures to the six illustrative scenarios (used as baselines) of SRES. That analysis has shown that the average GDP reduction with respect to the baseline in most of the stabilization targets considered (ranging from 450 ppm in the most stringent case to 750 ppm) is under 3%. By 2050 (year at which the GDP reduction reaches a maximum) the highest percentage reductions (between 3% and 4%) are experienced for stabilization targets of 450 ppm for scenarios of the A1 family. At a stabilization target of 550 ppm the average decrease with respect to the baseline is about 1%. For some scenarios the impact on GDP is even positive (i.e. it leads to an increase of GDP). Therefore, based on these considerations and to be on the conservative side, we are assuming that by 2050 the world GDP in this SD Vision, scenario could be 5% lower than in the original A1T scenario.

Of course, while this assumption is backed by various modelling exercises, it does not necessary solve the question of perception of costs. Various interest groups may have to bear proportionally higher costs, such as transition costs. Short-term costs will likely remain uncertain and controversial, despite the convergence of economic modelling on the long term. Their distribution will raise, both within and between countries, a number of social and economic issues. Most developing countries might refuse to bear the costs of emission mitigation beyond those actions that could bring ancillary economic or environmental benefits, in which case they would initially be supported by the richer countries.

There might be various methods to reduce cost uncertainties and controversies, and to deal with these various concerns – from indexing targets on economic output, price capping mechanisms, use of a wider Clean Development Mechanism or non-binding target for allowing developing countries to participate in emissions trading. Policy makers at country level could use a wide range of policies and measures to better deal with domestic concerns, while negotiators could find efficient ways to deal with those of various countries – from coal-rich to oil-exporting countries. Some costs will remain and be felt – but again the basic

assumption of this SD Vision scenario is that the willingness to address climate change, enhance security and energy access will prevail.

The combination of policy intervention, and individual progress towards increased energy efficiency, would also result in a decrease in total energy demand with respect to the initial reference. In typical modelling simulations of climate change mitigation policy, a result of this type could be produced as a result of increasing energy system costs, with the extent of decline in demand depending on the model used and the other assumptions of the model. In this case, the decrease in energy demand with respect to the original A1T case is driven by energy intensity improvement rates. Using this criterion, primary energy demand in the new scenario is about 15% lower than in the A1T scenario.

In the discussion that follows, it is important to keep in mind that, while the original A1T scenario used as a starting point was actually simulated by IIASA using the MESSAGE model, **the SD Vision scenario described in this section has not been generated by rerunning the same model, but by simply modifying the original output to fit the desired picture**. This is also the reason why the SD Vision scenario is only represented in primary energy terms and, except for the transport sector, we are unable to provide figures on final energy demand and its sector breakdown. Given the illustrative purpose of this quantitative description, full modelling of such a scenario was not felt to be necessary to the development of our thinking. Of course, to evaluate in a modelling framework the economic costs of attaining the goals indicated would certainly constitute interesting and useful work.

Box 3.2. Methodology

For further clarity and transparency, this box illustrates the quantitative manipulations performed on the original IIASA-MESSAGE results for the A1T scenario in order to arrive at a quantitative representation of our SD Vision scenario.

To meet the norms proposed, the following changes were made:

The GDP level and overall trajectory was lowered slightly (-5% with respect to the original projection for 2050) in each of the four world areas. Figure 3.1 shows the two trajectories.

Energy demand (with respect to the original projection) was lowered separately by world area as much as possible without producing, as a result,

rates of decrease in energy-intensity inconsistent with historical rates. Analysis carried out previously on historical trends found that only in periods following price shocks and sustained oil price increases have these rates of energy intensity decrease been of more than -2% per year. So even if the SD Vision scenario has sustained policy intervention, this sort of "rule" is not broken for more than two-three years in a row.

The energy demand that results from this process, aggregated to the level of the four regions, has a trajectory that is about 15% lower than the original one (Figures 3.2 and 3.3). Transport energy demand was lowered by the same amount.

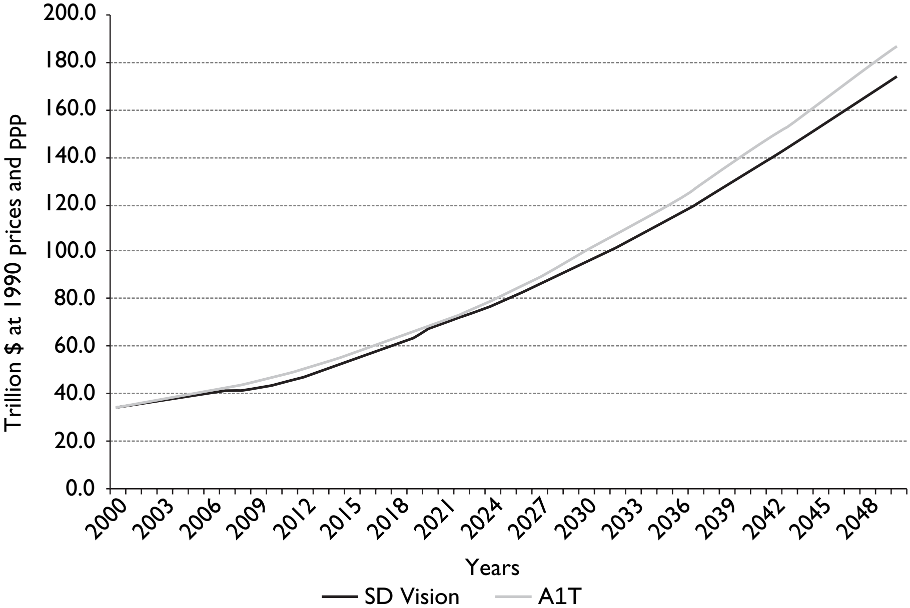
The percentage shares of the various fuels/energy sources in primary energy supply, as computed from the original A1T- MESSAGE scenario for each of the four regions, were modified. The modification consisted in general of increasing the shares of non-fossil fuel emitting sources and lowering the share of fossil fuels, but in some cases exceptions were made for coal, based on the fact that more coal was likely to be used to produce either synfuels or hydrogen. The new mix was applied to the previously computed new regional energy demand to obtain the new energy quantities. The oil share and the oil demand in the transport sector were determined in a similar way.

Carbon emissions were computed using average emissions factors from the year 2000 for the various fossil fuels (coal, oil, gas).

Total potential emissions at the year 2050 were computed in the hypothesis that all energy demand is satisfied by fossil fuel sources. The level of emissions corresponding to an energy system where 60% of energy demand is satisfied by non-carbon-emitting sources was also computed. The difference between these and the carbon emissions of the SD Vision scenario represent the amount of emissions that need to be captured and stored.

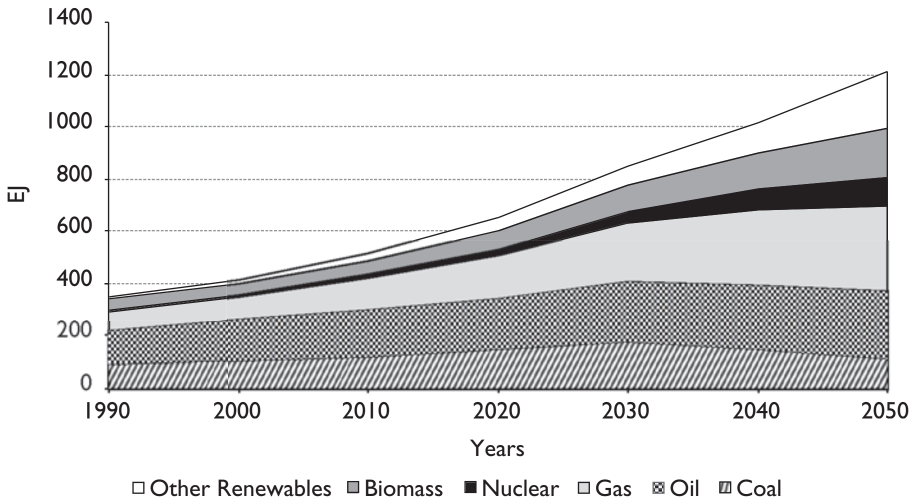
That amount was distributed among world regions based on such considerations as presumed CO_2 storage capacity (*e.g.* in oil and gas deposits, or in coal seams, etc.) and per capita incomes.

Figure 3.1 Comparing GDP Trajectories



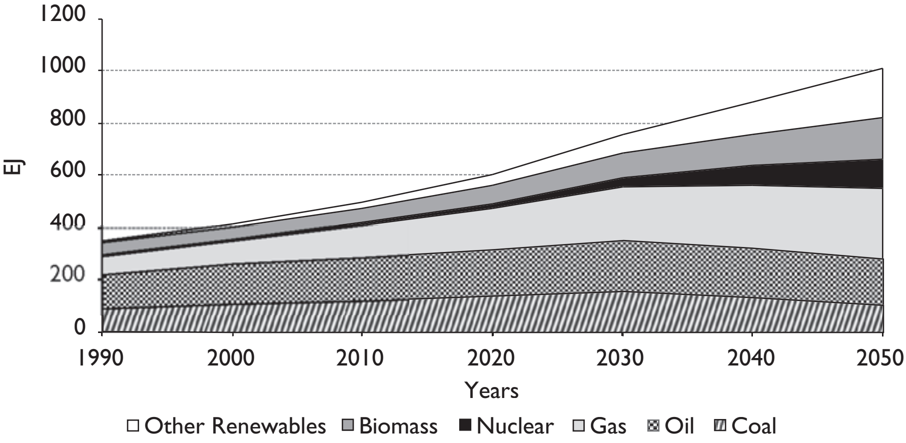
Source: Elaboration on data from SRES and IIASA.

Figure 3.2 The A1 T Scenario: World Total Primary Energy



Source: Elaboration on data from SRES and IIASA.

Figure 3.3 The SD Vision Scenario: World Total Primary Energy



Source: Elaboration on data from SRES and IIASA.

Before discussing the SD Vision scenario, several comments on the original A1T scenario are called for. First, as shown in Figure 3.2, it should be noted that the fuel/technology mix in the original A1T scenario already has a generous share of zero-carbon sources in its configuration (43%). In fact this result could be considered rather optimistic in view of the current technological performance and market penetration of renewables in general, and of the social acceptability of the nuclear technology at certain penetration rates.

Secondly, in the original A1T scenario, due to the "no new policy" assumption, the Kyoto protocol does not enter into force, the "carbon price" remains zero: hence carbon capture and storage technologies are not developed. The A1T scenario however includes also a number of other technologies such as those based on hydrogen from a variety of sources, coal liquefaction, and production of synfuels.

Finally, the A1T scenario has already a large share of fuels other than oil in the transport sector, and in fact more than meets the target set for the SD Vision scenario: only 37.3% of energy demand for transport is satisfied by oil and in fact, that oil even includes liquefied coal. The other transport fuels that can substitute for oil include: electricity; gas; hydrogen from various sources; liquid synthetic fuels from biomass; alcohols from coal and biomass.

With respect to the A1T scenario, the SD Vision scenario has a further increased share of these zero carbon sources, based on the assumption that proactive policies to achieve the target of 60% zero-carbon sources in

total primary energy supply by 2050 would further boost their share with respect to a scenario of no policy intervention (as the original A1T). The SD Vision case, illustrated in Figure 3.3, has about 46% non-fossil fuel sources in total primary energy. This relatively small increase in the non-fossil share of primary energy is largely achieved with a further increase in nuclear and renewables other than biomass. However, this means pushing nuclear generation to levels (11.3% of TPES and 114.5 EJ[9]) that by today's standards would be considered hard to accept socially, and perhaps pushing renewables to achieve market shares (15.7% for biomass and 18.9% for other renewables) that today would be considered very optimistic or very costly.

In order to get to 60% non-carbon emitting sources, it is assumed in the SD Vision scenario that CO_2 capture and storage technologies are able to store for the very long term almost 26% of the total CO_2 emissions from the fossil fuels (in primary sources) used in 2050. In this scenario, policies that favour carbon emissions reduction or control are actively pursued; hence carbon separation and long term storage are definitely part of the picture and in fact may allow for some increase in the share of coal used. This is likely to be felt necessary by a number of countries that might be either reluctant to develop the nuclear option, to bear the costs of higher shares of renewable (or deal with intermittence problems) or to give up abundant and cheap coal resources.

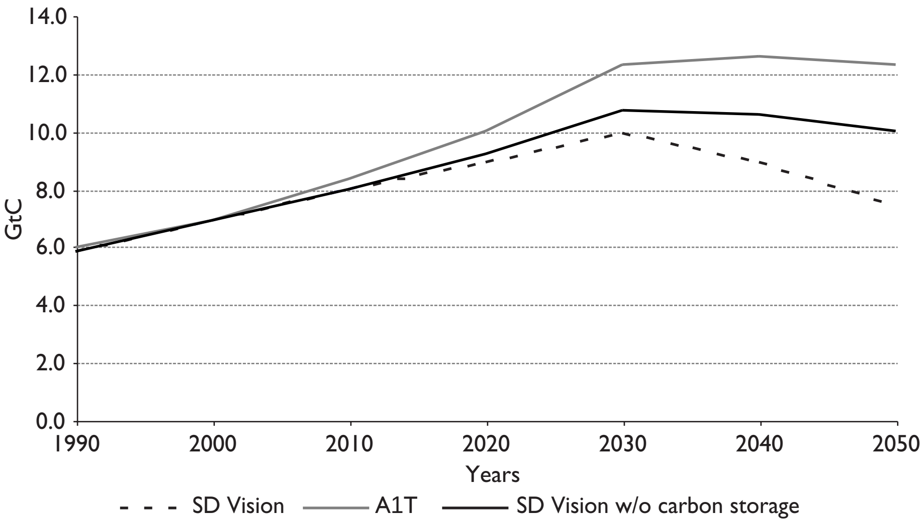
As can be seen from Figure 3.3, the share of gas would grow, reaching 26.4% of TPES, with demand increasing threefold in absolute value with respect to present levels. On the other hand, the share of oil and coal would decline to 18% and, respectively, less than 10%. But while for oil total demand would be still 16% higher than in 2000, for coal it would already be lower.

Most of the oil consumed (about 73%) would be used in the transport sector. However, oil would represent 38% of total transport energy demand, the rest being satisfied by other energy sources (electricity, gas, hydrogen, bio fuels, and synfuels). As mentioned, no improvement was needed on the original A1T scenario in this case. In fact, with respect to that scenario the share of oil in transport demand is slightly higher in the SD Vision scenario, but overall oil consumption in transport is lower.

9. Note that total primary energy supply in the IIASA A1T scenario, on which the SD Vision scenario is based, is computed using an accounting convention for nuclear power that is different from the one used in IEA energy balances. The IIASA considers the electric output of a nuclear plant as being a primary energy source (as if it assumed a 100% efficiency of transformation from primary heat into electricity). The IEA considers that the heat is the primary energy source and then assumes a 33% efficiency. As a result, the value in primary energy of a kWh of nuclear power produced today according to IIASA's methodology is roughly one third of that of the same kWh according to IEA methodology.

In the SD Vision scenario CO_2 emissions would peak around 2030 at about 10GtC and then start declining, to return to year 2010 levels by 2050 (Figure 3.4). With respect to the A1T scenario, emissions would peak about a decade earlier and at a lower level. This would make the SD Vision scenario consistent with a goal of CO_2 concentration stabilisation of 550 ppm by the end of the 21st century and with a cumulative emissions profile of rather less than 1000 GtC over the century. Table A.II.8 in Appendix II provides more detail on the SD Vision scenario at the aggregate World level.

Figure 3.4 Comparing Carbon Emissions Trajectories



Source: Elaboration on data from SRES and IIASA.

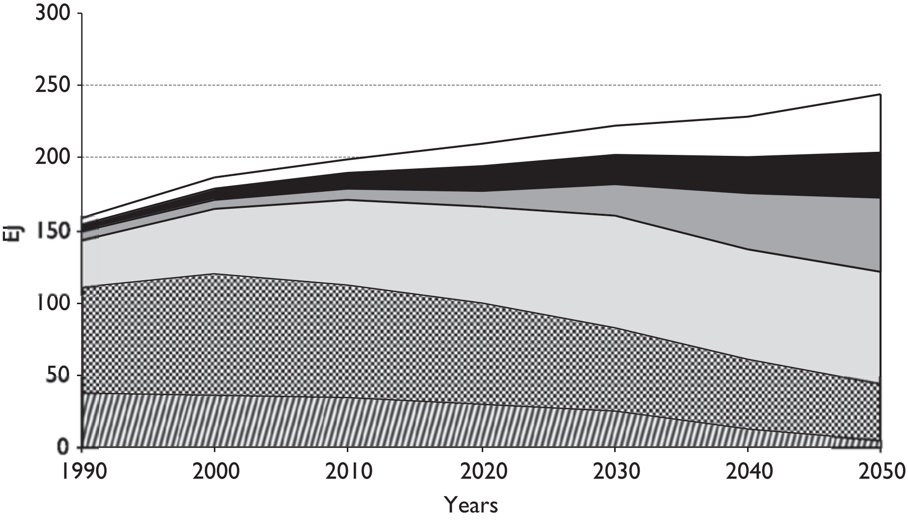
This scenario therefore has been constructed to broadly satisfy the first two requirements (or norms) set at the beginning of this exercise. Concerning the third – providing access to electricity to at least 95% of the world population – the other characteristics of this scenario provide strong indications that this challenge would also be met. To a large extent, the challenge comes from the fact that the increase in population projected over the next 50 years will be concentrated in the developing countries and that this group includes all the poorest countries in the world. However, the income growth rates assumed by this scenario for developing countries should provide sufficient resources to accommodate at least the basic energy needs of the population of these countries. Also, we can assume that in developing countries the trend towards increasing urbanisation of the population will continue. While this process will bring along serious

problems of environmental pollution at the local level, it will make it much easier to provide a large portion of the increase in population with access to the electricity grid. The improvement of renewable energy technologies and of distributed generation could provide a significant share of the remaining rural population with a local supply of energy without building expensive transmission infrastructure to bring electricity to remote areas. Finally, one could argue that if trends to electrification experienced in the last twenty years (at rates of 70 to 120 million people gaining access to electricity every year, as estimated by the IEA in the WEO 2002) continue over the coming 50 years, the target would be largely met by 2050. However, it is known that the fast electrification trends seen in the last two decades are largely the results of the gigantic effort – and strong political commitment made by China in this direction. For these trends to continue into the next half century and to take hold in the rest of the developing world, both income (generated by the assumed economic growth) and a similar political commitment will be needed.

Regional Implications of the SD Vision Scenario

Figure 3.5 and Table A.II.9 in Appendix II provide more detail about the distribution of total primary energy supply in the SD Vision scenario in OECD countries.

Figure 3.5 SD Vision - OECD: Total Primary Energy



Source: Elaboration on data from SRES and IIASA.

This of course represents an average picture of the energy system in countries spread over three continents plus Oceania; it therefore hides large differences at the national level. However it provides a clear view of the structural modification that present day energy systems (as well as energy use patterns) in the developed world would need to undergo in order to meet the challenges posed by this SD Vision scenario.

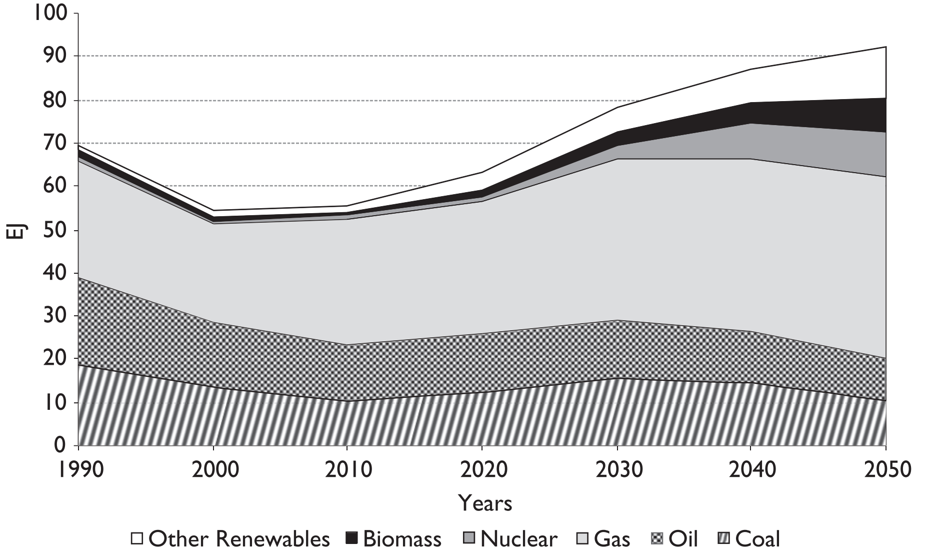
Total energy demand of the OECD area increases by 31.5% over the period 2000-2050. Of the four macro-regions considered, the OECD area is the only one that by 2050 would rely on zero carbon-emitting energy sources for more than 50% of its needs, up from a current level of about 11.7%. This would imply an almost four-fold increase in energy from biomass, a more than six-fold increase in other renewable energy production and more than seven-fold increase in nuclear power. On the other hand, coal use would be 14% of the present level, and oil use would be 46.7% of the current level. All of that oil would be used in the transport sector, where it would be augmented by synthetic oil from coal liquefaction; in fact, almost all the coal used would be converted to synfuels for transport. In this mix, oil products would meet almost 45% of energy demand for transport, while the rest would come from other sources (gas, hydrogen from various sources, bio fuels)[10]. Gas would be the only fossil fuel to see an increasing use, growing by 72%: most of that used within the OECD region would be imported. Changes in this region as depicted by this scenario are truly dramatic.

Concerning the former Soviet Union and Eastern Europe (the REF region), the projected energy demand increase is 69.4% between 2000 and 2050. Figure 3.6 and Table A.II.10 in Appendix II show a much less dramatic change in fuel mix than in the OECD case. Once economic growth recovers, this area, which is expected to grow only marginally in total population, would start increasing its energy demand.

Reliance on abundant natural gas resources would grow despite increasing gas exports, while oil resources are to a significant extent exported and slowly depleted. Gas is the main basis for the transition to a less carbon intensive world. However, while its use keeps increasing, its share peaks in 2010 at 53% of total primary energy and declines to 45% by 2050. Over time, increasing amounts of gas would be reformed to produce hydrogen, especially for use in the transport sector.

10. If we exclude synthetic oil, the share of oil in transport energy demand goes down to 40%.

Figure 3.6 SD Vision - REF: Total Primary Energy



Source: Elaboration on data from SRES and IIASA.

Coal resource use would increase again to 2030, and then decrease as non-carbon alternatives conquer larger shares of the market. However, increasing amounts of coal would be gasified or liquefied.

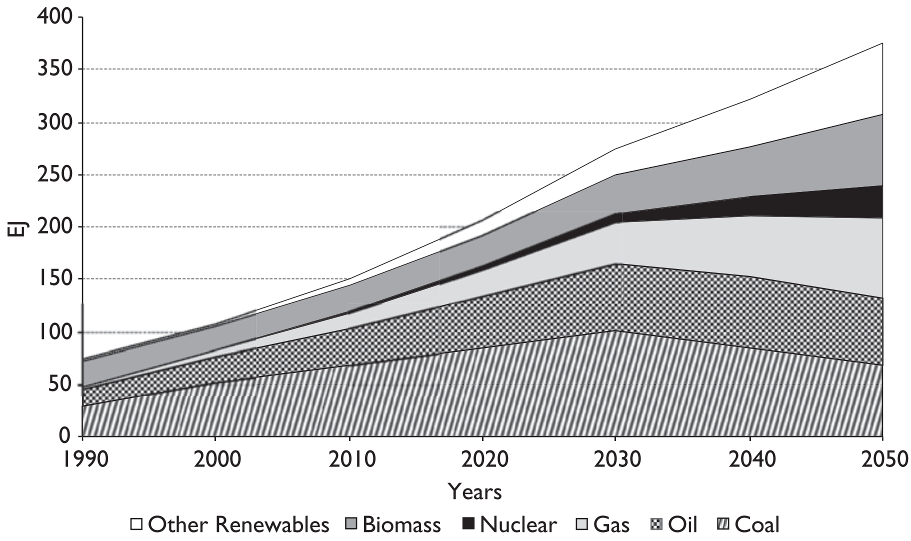
Nuclear generation would increase thirteen-fold by 2050, expanding its share more than sevenfold. Biomass energy production would also increase nearly seven-fold, quadrupling its share, while other renewables would increase their output nine-fold and quintuple their share.

By 2050 only 16% of total energy for transport would come from oil, the rest being provided by gas (either directly or stripped of its carbon and transformed into hydrogen) and coal based fuels, by bio fuels and electricity.

In the rest of Asia, energy demand would grow at a steep rate following population increase and successful economic expansion (Figure 3.7 and Table A.II.11 in Appendix II). By 2050 energy demand will have increased 247.5% with respect to 2000. This growth until 2030 would rely significantly on available coal resources, and on increasing oil imports for the rapidly growing transport sector. After 2030 coal use would start declining both in share and in absolute terms, and fall to about 17% of total primary energy. Gas, on the other hand, will keep increasing until 2050 overtaking both oil and coal in terms of share of primary energy. Oil consumption would only start to decline after 2040, but by 2050, 83% of that oil would be for transport use. Oil would represent

42% of total transport energy demand while the remaining 58% would come from other sources (electricity, bio fuels, hydrogen from natural gas or coal).

Figure 3.7 SD Vision - ASIA: Total Primary Energy



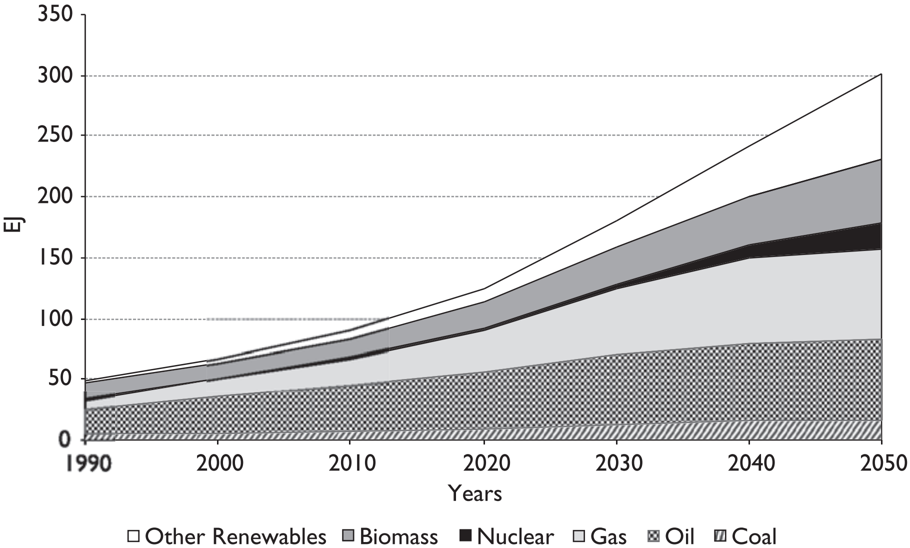
Source: Elaboration on data from SRES and IIASA.

Among non-carbon sources, energy production from biomass would gradually increase from an already strong initial base, reaching about 18% in 2050. However, while growing in absolute terms, its share would decline until 2030, as gas or liquid hydrocarbons take an increasing share of traditional biomass uses. Biomass use starts growing again after 2030, when more advanced biomass based technologies penetrate the market. The other renewable sources would grow even faster – to 24 times their initial level and from a 2.7% share to more than 18%. But the most spectacular growth would be that of nuclear, increasing to 62 times its (low) initial value, to reach an 8% share by 2050.

The last macro-region (ALM) is composed of a heterogeneous group including Africa, the Middle East and Latin America (figure 3.8 and Table A.II.12 in Appendix II). This group is expected to almost double its population over the next 50 years, and to enjoy a sustained economic growth. This means that energy demand growth would show little signs of slowing down through 2050, increasing by 344.4% with respect to 2000. The region would continue to rely significantly on oil and gas, of which it

has abundant resources, but which to a significant extent will still be exported. Biomass production and other renewable energy production would represent about 40% of total primary energy by 2050. Nuclear energy would start making a contribution only after 2020 and provide another 7.7% of total primary energy by the end of the period. Coal would maintain a small share.

Figure 3.8 SD Vision - ALM: Total Primary Energy



Source: Elaboration on data from SRES and IIASA.

Regarding the transport sector, 33.6% of its energy demand would be covered by oil (and most of that would be consumed in oil exporting countries), the rest being supplied by gas and bio fuels or synfuels from coal. This lower dependence from oil of the transport sector is to some extent explained by the availability of gas and/or biomass in these countries.

Policy Implications

As mentioned above, by construction this scenario produces a world in which energy demand and GHG emissions in 2050 meet the targets set. There are, of course, numerous alternative scenarios that might also meet these same goals – and the reader may not share the particular vision that

emerges from this one or agree with any of the specific numbers set forth. In fact, we are aware of the risks inherent in any quantitative scenario, which very easily favour a shift of focus away from policy issues and toward a debate over specific numbers and figures.

The main reason for trying to provide a quantified version of this scenario is to provide a sense of the scale of some of the energy and environmental challenges that lie in the future. Such a scenario stimulates a discussion on the path – even if this is not "it" – that would have to be undertaken to meet such goals. With this crucial caveat, we may thus usefully begin to look at some of the policy implications, i.e. determining what short- and mid-term targets or milestones might be needed and what type of policies could have to be implemented to achieve them.

A useful point of departure for this is offered by an examination of some indicators for the SD Vision scenario, focusing on the relationship between energy use, income growth and carbon emissions. As shown by table 3.1, world energy intensity in the SD Vision scenario decreases at a yearly rate of about 1.5% over the period 2000-2050. This rate is higher than the average rate computed from IEA historical data for the period 1971-2000, a value closer to -1.1% per year, and higher than the rate of energy intensity decrease assumed by the WEO-2002 (about -1%). The rate is not constant: over the past 30 years, there have been short periods in which the rate of decrease of energy intensity has been much higher – up to 2.5%. Between 1990 and 1999 the rate of decrease of energy intensity has been on average 1.5% per year, and this is during an historical period without remarkable increases in energy prices or particularly aggressive efforts to conserve energy (i.e., it migh be considered as "autonomous energy efficiency improvement"). This suggests that energy-intensity reductions like the ones envisaged by the SD Vision scenario would take some political will but that they need not have punitive effects on the economy.

On a regional basis, the energy-intensity improvement required by this scenario would be even more modest for an area like the OECD. This makes sense for several reasons, including the fact that many OECD countries already have relatively low energy intensities per unit of GDP compared to most developing countries, and that the rate of growth of OECD countries economies is expected to be lower than in developing countries. Per capita energy consumption would even slightly increase in this scenario for OECD countries. However, the reduction of per capita carbon emissions is significant.

Regions like Eastern Europe and the former Soviet Union (REF) still have a lot of room to improve their energy intensity, both by increasing economic growth and by significantly modernising their energy infrastructure. A 2.2% yearly rate of energy intensity decrease for this area in the SD Vision scenario reflects this fact, although the area does not reach the energy intensity levels of the OECD. Carbon intensity is slashed dramatically over the period. Per capita energy and per capita carbon emissions both grow in this area.

Table 3.1 SD Vision Scenario – Selected Indicators

	2000	2010	2020	2030	2040	2050	2000-50
							Yearly % change
WORLD							
Energy intensity 10^6J/$ - PPP	12.455	11.553	9.318	7.974	6.696	5.850	-1.50
Per capita energy 10^9J/cap	68.007	72.096	79.338	92.440	102.983	116.382	1.08
Carbon intensity kg/$	206.475	185.722	141.677	112.601	80.527	57.687	-2.52
Per capita carbon t/cap	1.127	1.159	1.206	1.305	1.238	1.148	0.04
OECD90							
Energy intensity 10^6J/$ - PPP	10.466	9.970	7.805	6.824	5.852	5.288	-1.36
Per capita energy 10^9J/cap	202.176	206.388	208.101	213.649	214.374	226.094	0.22
Carbon intensity kg/$	176.699	159.904	114.446	88.286	60.398	43.832	-2.75
Per capita carbon t/cap	3.413	3.310	3.051	2.764	2.212	1.874	-1.19
REF							
Energy intensity 10^6J/$ - PPP	24.226	21.990	17.714	13.824	9.919	7.993	-2.19
Per capita energy 10^9J/cap	129.833	130.134	146.031	180.424	201.294	217.909	1.04
Carbon intensity kg/$	433.825	377.717	290.912	214.922	137.479	94.778	-3.00
Per capita carbon t/cap	2.325	2.235	2.398	2.805	2.790	2.584	0.21
ASIA							
Energy intensity 10^6J/$ - PPP	13.078	12.413	10.044	8.443	6.835	5.964	-1.56
Per capita energy 10^9J/cap	33.180	41.654	52.416	66.329	75.735	89.090	2.00
Carbon intensity kg/$	227.204	215.538	169.198	134.408	92.152	64.825	-2.48
Per capita carbon t/cap	0.576	0.723	0.883	1.056	1.021	0.968	1.04
ALM							
Energy intensity of 10^6J/$ - PPP	13.178	12.340	9.830	8.493	7.256	6.111	-1.53
Per capita energy 10^9J/cap	44.503	48.575	55.851	70.376	86.440	100.822	1.65
Carbon intensity kg/$	176.561	164.751	125.698	103.751	80.140	56.602	-2.25
Per capita carbon t/cap	0.596	0.649	0.714	0.860	0.955	0.934	0.90

Source: author's computations based on SD Vision scenario output.

Trends in Asia show an energy-intensity reduction of about 1.56% per annum over the period in the SD Vision scenario and a carbon-intensity reduction of nearly 2.5% per annum. Income growth plays a major role in the trends for both indicators, both directly and as a result of the technological leapfrogging that could result from this economic growth. Per capita energy consumption, as expected in increasingly affluent societies going up the ramp of industrialisation, would increase at a yearly rate of 2%. Per capita carbon emissions would go up too, but at half that rate.

As for the rest of the world (Africa, Middle East and Latin America), the rate of energy -intensity reduction would match the rate of Asia (1.53% per annum) in this scenario. Similarly the rate of carbon-intensity reduction would be about 2.25% per year. While the income growth experienced by this macro-region would likely be less dramatic than in Asia, the impact on per capita energy consumption would remain impressive (1.65% increase per annum) and per capita carbon emissions would also grow.

The SD Vision scenario has to a large extent been built on the assumption of robust economic growth, especially in developing areas. But this growth is also to some extent a condition for a rapid transition to a more energy efficient and less carbon-intensive world. In other words, to be able to achieve the targets set for this scenario, energy and environmental policies must be designed in such a way that the world economy remains vibrant. These policies, however, must also ensure that technological progress (rather than intensive resource use) remains at the heart of economic growth.

The picture described by the SD Vision scenario is certainly much less reliant on carbon -based fuels than the present world. Although it does contain some significant departures from present trends, it is not a wildly different world from that which we see today. Thus, for example, we have not made any explicit hypothesis about revolutionary technological breakthroughs emerging in the coming fifty years that provide a miraculous solution to global or national problems. Instead, this scenario contemplates mostly improvements (albeit at times dramatic ones) of technologies already existing or at the laboratory stage. Neither have we assumed revolutionary changes in the basic energy services that will be demanded in the future, although the way they will be satisfied may be significantly different. In this sense we have described a transitional world to something that *could* be very different.

Nevertheless, moving to the world depicted poses some daunting challenges and has some strong implications in a variety of policy areas ranging from energy to environmental and R&D policy. The quantitative framework constructed in the previous section and the data shown in Table 3.2 below helps us examine more closely some of those challenges.

Table 3.2 Yearly Growth Rates of Total Primary Energy by Source in the SD Vision Scenario versus Historical Data: Period Averages.

	Historical Data*			SD Vision Scenario			
Total Primary Demand	**1971-2000**	**1990-2000**	**2000-2010**	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Biomass	1.74	1.5	1.40	2.70	2.90	2.50	3.00
Other Renewables	3.23	3.4	5.75	6.00	4.50	5.60	4.65
Nuclear	11.5	2.5	3.55	4.50	8.00	7.00	4.00
Coal	1.70	0.7	1.10	1.37	1.41	-1.60	-2.45
Oil	1.30	1.3	0.67	0.75	0.77	0.01	-0.55
Gas	3.00	2.2	3.55	2.57	2.76	1.77	1.00

* Sources: IEA *WEO 2002*; IEA *Renewables Information 2003*.

Table 3.2 compares yearly growth rates of total primary energy supply by source in the SD Vision scenario with historical growth rates.

Postulating an increase in the share of non-carbon-based energy resources (which grow from the present 16.5 to almost 46%), in this scenario implies going from an aggregate production level of 68.5 EJ in 2000 to 465.3 EJ in 2050, almost a seven-fold increase. Considering that we are dealing with an aggregate of technologies and resources, rather than with only one technology/resource, the magnitude of the change is not something unheard of in past transitions occurring in comparable time scales (Nakicenovic *et al.*, 1998). Much more extraordinary changes happened either in the first or in the second half of the 20th century. The challenge, however, is not a small one and it becomes clearer if we consider the main components of this non-carbon emitting energy supply.

Renewables

Renewables in 2001 were estimated at 13.5% of total primary energy supply worldwide (IEA, 2003a), taking into account both commercial and non-commercial energy sources. Of this share, 80% was supplied by biomass and waste, 20% by hydro-power and other renewables. However, the situation varied significantly between the regions of the world. While

in OECD countries renewables represented 5.7% of TPES of the area, they supplied over 50% of TPES in Africa, 33% in Asia and 28% in Latin America. Also, while in the OECD area most of renewables sources are used to generate electricity, in the rest of the world most of them are used directly in the residential, commercial and services sector. Despite this, renewables provide more than 18% of global electricity production worldwide.

Increasing the share of biomass production in TPES from almost 11% in 2000 to 15.7% in 2050, as envisaged by the SD Vision scenario requires a more than three-fold increase in production. At present the rate of increase in world biomass energy supply is only slightly higher than the rate of growth of TPES, with production increasing faster in OECD countries (1.8% per annum). To achieve a share like the one envisaged in the SD Vision scenario, the rate of growth of global biomass supply over the coming 50 years must be almost twice as high as the one experienced in the past 10 years.

Presently about 87% of biomass used in the world for energy production is used outside OECD countries, and much of that is non-commercial biomass (IEA, 2003a). This should change in the future, with biomass becoming more and more a commercial form of energy, especially if production at the scale projected for 2050 (159 EJ) is to be sustained. Biomass plantations at this scale would require devoting increasing land to this use, potentially leading to stronger competition with food production. In addition, marginal land may not be suitable for such crop systems – particularly a problem in dry areas.

In most areas of the world an increase in biomass production of that magnitude and at affordable costs requires significant progress in agricultural and soil improvement techniques; the shift may be the equivalent of another "Green Revolution" such as that in food production experienced over the past century, and perhaps including the application of bioengineering techniques to improve plant yields. In some developing countries realising this type of change requires providing appropriate training to farmers, money to buy improved seeds and agricultural machinery. Biomass production in the oceans may have to be considered, together with the potential environmental impacts of this production. Furthermore, a substantial reduction in costs and improvements in the energy transformation efficiency would be called for if biomass were to replace oil and gas in the production of liquid and gaseous fuels.

The progress made in the last two decades in the general field of biotechnologies and agro technologies suggests that much can be done in this area. Energy transformation processes can likely get a helping hand from these same technologies in the form of specially engineered bacteria and algae. But more R&D would be needed.

For the other renewable energy sources (hydro, wind, solar PV, solar thermal, solar concentrating technologies, geothermal, etc.) increasing the share from 3.6% in 2000 to 18.9% in 2050 requires a thirteen-fold increase in energy output. This means sustaining, over the coming 50 years, growth rates between 4.5 and 6% per annum, which could be attained based on historical rates of 3.4% in the years 1990-2000.

The remaining potential for hydropower is very limited in Western Europe and in arid areas (and increasingly controversial almost anywhere): in those areas only a small fraction of the required output increase can be expected to come from new dam projects. On the other hand, the potential is still very large for hydro-power in North America and in many developing countries. The rest of the renewable energy supply would have to come from wind, from the various solar options and in a few cases from geothermal resources. While wind technologies have improved significantly in the last 15 years and this form of power generation has grown at a very fast pace in various OECD countries, its potential in those densely populated areas may not take long to reach saturation. Wind power can grow much more in the developing world. In general, it is from developing countries that much of the expansion of renewable energy supply is expected.

However the intermittence of power supply from wind and solar sources remains a problem. Possible solutions include either additional back-up capacity (which increases costs) or an improvement of power storage systems (which is difficult to achieve without substantial research work). In the case of solar-based power technologies, the efficiency of transformation of solar radiation into power is still low – although the transformation into heat to produce either hot water or electricity is much better. To increase significantly their contribution to primary energy supply, dramatic improvements in conversion efficiencies, or in materials cost reduction are needed. However, at least in the "sunny belt", solar-thermal electric power offers solutions to solve the intermittence problem by simply (and cheaply) storing the heat before it is transformed into power.

A fairly established technology – albeit one which would benefit from improvements in a number of technology areas (especially corrosion resistant materials) – is geothermal energy. Untapped resources are still significant in practically all world regions, although closeness of geothermal sites to energy demand limits the choices.

Summarising, for renewables achieving the market penetration rates indicated by the SD Vision scenario would require aggressive policy intervention. Deployment and market development policies should be implemented as soon as possible to prepare for the acceleration that should take place, especially for non-biomass renewables, after 2020. Market deployment could be promoted through economic incentives, feed in tariffs, renewable portfolio standards and green certificate trading for power from renewables, as well as taxation of environmental externalities. In parallel, public R&D policies would be needed to improve conversion and power or energy storage technologies, reduce the intermittence problems and lower the overall cost of these systems. Finally, adequate technology transfer and investment policies are required if the potential for renewables development is to be tapped where it is largest, i.e. in developing countries. However, while the available portfolio of policies is very wide, these policies would need to be pursued much more aggressively than they have been so far, and there would need to be a continuity of price signals to the renewables industry if the goals are to be reached. A carbon tax increasing over time or, perhaps more likely, a market for carbon reductions would provide such a signal. Besides, a carbon price signal could stimulate other technologies too (*e.g.* nuclear) and make their economics more attractive. This type of policy effort would likely emerge first in developed countries, so as to allow significant technology learning and cost abatement to take place in these technologies before being introduced at a large scale in developing countries.

Nuclear Power

The other component of the non-carbon emitting energy supply is nuclear. This technology, according to IEA data and following the IEA accounting convention for energy balances, presently supplies 6.9% of world TPES[11] and 17% of world electric power. The shares are higher for OECD countries (respectively 11% and 23%), and much lower for developing countries (respectively 2.4% and 6.1%). Figures are different if we follow the convention used by IIASA[12] in the elaboration of its A1T scenario (which

11. See footnote 9 in this chapter for the differences between the various conventions for accounting for nuclear output
12. See footnote 9 in this chapter.

forms the basis of the SD Vision scenario). Using that methodology, the share of nuclear is equal to about 2% of world TPES, 3.7% of TPES in the OECD and 0.6% of TPES in the developing world. In the discussion that follows it should be clear that figures use the IIASA convention.

Thus, increasing the share of nuclear power in a growing TPES, as indicated in the SD Vision scenario (i.e. from 2 to 11.3%, following the latter convention), would imply a fourteen-fold increase in nuclear energy production worldwide, a substantial increase by any standard. Table 2 shows that this would require a rate of growth of nuclear power supply above 3.5% per year over the entire period, and for some decades as high as 8%. These may seem impossibly high compared to the rate of growth experienced in the decade from 1990 to 2000 (during which it was 2.5%), however, looking back to the rate of growth of 11.5% experienced from 1971 to 2000 these rates seem much less out of reach.

This is not to downplay the extent of the effort required, especially in the current public opinion context for nuclear energy. Thus, in the scenario described, the resumption of nuclear plant construction would start at a more moderate pace for the two decades from 2020 to 2040. To allow for such a growth in nuclear power the biggest problem is that of reducing the risks – and perceived risks – stemming from nuclear accidents (both involuntary and voluntary, e.g. terrorism), from long-term radioactive waste storage and from nuclear weapons proliferation. These perceived risks may, in particular, preclude the international community help developing countries face the high up-front costs of nuclear power – as they currently prevent nuclear projects in the Clean Development Mechanism of the Kyoto Protocol.

It may prove difficult for the public in several OECD countries to accept nuclear plants in the landscape at a scale necessary for this energy source to achieve a market share of 21% by 2050. This would require a more than seven-fold increase in output – and an increase approximately of the same magnitude in power generation capacity. While this would not bring the average country to the level of France (where nuclear energy currently represents 42% of TPES), it might be unacceptable in many countries. Even if objections were overcome by a change in public attitudes, the problem of long term disposal of radioactive material would remain serious: clearly such an ambitious nuclear renaissance plans would require higher levels of safety and significantly lower levels of radioactive waste production. New concepts and new reactor designs would have to be commercially available no later than 2025 if nuclear energy is to grow to the level envisaged.

A number of new reactor designs are currently being studied that address some of the concerns just mentioned. However a current opinion among nuclear scientists is that R&D efforts underway on innovative nuclear reactors receive a fraction of the funding supplied between 1950s and 1970 to develop the current generation of nuclear reactors. Nuclear R&D expenditures today are aimed primarily at maintaining and enhancing the performance of operating reactors. Assuming that low investment will continue, commercial availability for most of the design being developed could require 10 to 15 years or longer (see IEA/NEA/IAEA, 2002, p. 81). In a context of increasingly privatised and liberalised markets this type of trend may well continue, hence government support in the R&D area may be required again if the goals set in the SD Vision scenario are to be achieved.

The security and safety concerns of the Western world have so far greatly limited the potential expansion of electricity supply from nuclear technology in the OECD and brought to a standstill many large construction programmes started after the first oil price shock in 1973. Increasing doubts about the peaceful use of new nuclear programmes in some developing countries could lead to a slow-down in such programmes (although international monitoring schemes may alleviate such concerns). These issues exacerbate the rates of technology transfer, adding to the problem of the massive investments, and the build-up of an adequate technological capability that would be required in many developing countries to achieve by 2050 the output levels envisaged in the SD Vision scenario. Thus, while a global market share of 11.3% is *technically* possible, it might be economically challenging even in a high growth world.

Fossil Fuel Resources

Although the SD Vision scenario posits a decrease in the share of fossil fuel sources in the energy base, this does not imply that fossil fuels are not still used, or that there is a halt in the improvement of fossil-based technologies. Quite the opposite; for this scenario to be realised, technology improvement would have to be significant in all areas from fossil fuel resource extraction to their transformation and in energy end use. A number of factors support this contention.

As shown by table 3.2, oil demand in this scenario grows at around 0.7% until 2030 and then stalls and starts declining. This represents a much slower rate of growth than that experienced even in the past decade,

signalling the need for aggressive policy intervention. In absolute terms, the net increase between 2000 and 2050 is approximately 18%.

Gas demand growth in this scenario is robust and remains above 2.5% per year (and above the rate of growth experienced since 1990) until 2030, likely driving up prices, then starts slowing down until the end of the period. In absolute terms gas demand triples over the 50 years considered. Contrary to the other two fuels, gas demand does not start decreasing in the 50-year horizon considered. Most of the growth in this demand would take place in the developing world (particularly Asia, Africa, Middle East and Latin America) although it would be significant, in absolute magnitude, in OECD countries as well.

Coal demand grows very slowly until 2030 (although faster than in the period between 1990 and 2000) and starts a rapid decline afterwards. Coal demand picks-up speed between 2010 and 2030 in a period in which oil and gas prices are likely to be increasing. However coal demand in 2050 reaches a lower absolute level than in 2000.

The cumulated resource use between the year 2000 and 2050 for the SD Vision scenario would thus be:

- for coal to 6459.4 EJ (equivalent to 154.3 Gtoe);
- for oil to 9131.7 EJ (equivalent to 218.1 Gtoe, or 1603 Bbl);
- for gas to 9203.2 EJ (equivalent to 219.8 Gtoe or 230 Tcm).

These figures must be put in the right context; they must be compared with proven reserves and with the resource base of coal, oil and gas [13]. Estimates of both reserves and resources tend to differ across different data sources and are constantly revised as new knowledge becomes available: we must bear in mind that these estimates are not written in stone. However, today's knowledge of these stocks allows us to draw a few conclusions.

For coal, at the level of resource use indicated by the SD Vision scenario no shortage can be anticipated. While the resource adequacy could hold for the foreseeable future, coal depletion in this scenario may well take place faster than in a more hydrocarbon-oriented scenario.

13. The term reserves refers to resources that have been discovered and are expected to be economically producible; the resource base includes, besides proven reserves, also undiscovered resources that are believed, with various degrees of confidence, to be available in the ground. Furthermore for oil and gas the distinction is often made between conventional (produced from underground hydrocarbon reservoirs by means of production wells) and unconventional (others, such as oil shales and oil sands, gas from tight sands and shales, coalbed methane) reserves and resources (IEA, 2001c).

On the other hand, at consumption rates like the one envisaged by the SD Vision scenario remaining discovered reserves of conventional oil, estimated at 130.5 Gtoe (IEA, 2001c) would largely be depleted by 2050. By then the world would be tapping into conventional oil resources that yet remain undiscovered, as well as drawing significantly from what are currently considered unconventional resources.

Finally, remaining proven reserves of conventional gas, estimated at 157.6 Gtoe (IEA, 2001c) would be also gone by 2050; under this scenario, presently undiscovered resources would be under exploitation. Altogether, based on current estimates of the conventional gas resource base, resources would be sufficient to cover a cumulated demand of the size envisaged by the SD Vision scenario, but by 2050 nearly one half of this resource would be depleted– a relatively fast depletion rate for global gas resources.

These considerations bear some important implications for hydrocarbon resources exploration, extraction and related technologies. For oil the issue is that easily accessible resources are rapidly being depleted and new deposits being found are on average smaller and less accessible than those discovered 50 years ago. The problem is going to get worse and unless exploration and extraction technologies improve, finding oil and pumping it out of the ground will become more and more expensive. In this scenario technological change is more rapid in non-fossil-based technologies but there is no reason to believe that it will come to a halt in other sectors. Also, technologies would have to improve if unconventional oil resources are to be tapped. At present, unconventional oil, especially in North America, is already commercially produced but technologies to reduce the energy input per barrel of oil and refined products need still to be improved in order to reduce associated CO_2 emissions.

Likewise, in the case of gas, the rapid expansion of demand envisaged by this scenario will have to be matched by a similar expansion in supply. Much of the know-how developed for oil exploration will be useful here, and more will have to be developed to find new resources and to reach deposits located deeper in the earth crust, offshore or in extreme climates. Several other technologies need particular attention if the gas market is to develop to its full potential. First of all, improved and more resistant materials for pipeline transport of gas as well as more effective pipeline monitoring systems will be needed both to reduce to a minimum the losses in the system and to maintain its security and safety. Improved technologies will be also required to transform natural gas (or other gases like coal bed methane) into liquid hydrocarbons and oil products (gas-to-

liquids technology). These technologies will be especially needed to get to market large amounts of "stranded gas", i.e. found in very remote or in very unstable areas or in otherwise extreme conditions. While the basis for these technologies was developed in the early part of the previous century, lowering the energy input for the process, increasing its yield and lowering the costs will need further work.

Other important implications of this scenario concern the infrastructure to transport both oil and gas resources, and the geopolitical framework. A tripling of gas demand requires an expansion of the transport infrastructure of roughly the same proportion. The speed of development of that infrastructure would have to match that experienced in the oil trade between 1940 and 1980, or more. However, there would be one key difference: not all gas trade can take place by pipeline, a lot of it will have to occur via tankers in liquefied form, which poses more problems than oil tanker traffic. Liquefaction and re-gasification stations will be needed at supply and demand points.

As demand grows faster in the first half of the period, the timely building of the corresponding infrastructure might be complicated, both due to the significant construction lead-times involved and the sheer magnitude of the investments to be mobilised. In addition, the potential safety issues and environmental problems that this trade could pose are still insufficiently appreciated and will need to be addressed with appropriate technology and rules. Furthermore, to reach the consumption markets much of the gas traded today has to cross several country borders and to pay transit fees. In a relatively calm international political framework this should not pose serious problems, but in presence of regional conflicts the risks and difficulties may be significant.

One element that should not be entirely overlooked is the potential, in the SD Vision scenario, for the creation of new dependence and vulnerability problems with respect to gas supply. While in terms of fuel mix the share of gas in TPES does not reach levels attained by oil in the 1970s, and the geographic distribution of natural gas reserves is not as concentrated as with oil, half of world gas reserves are located in two countries: Russia and Iran. Over time, as more dispersed resources are depleted, a problem of dependence on gas supplies from these two areas could develop in terms not very different from present day dependence on Middle Eastern oil.

The problem of dependence on outside sources is potentially serious for resource-poor OECD regions like Western Europe, Japan and the USA. While this scenario incorporates a strong drive towards diversification of

fuel sources, especially away from oil, which would help ease tensions on oil demand, compared to other scenarios, much of the diversification would only emerge late in the scenario period. Furthermore the goal of reducing CO_2 emissions would put more stress on the gas market, at least temporarily. Increased coal use, which could reduce pressure on the oil and gas market, is not envisaged in this scenario, due to the high carbon dioxide emission connected to it. Gas plays the role of a transition fuel towards a low-carbon-emission world but, as shown by table A.II.8 in Appendix II, for OECD countries vulnerability to supply shocks in the gas market is highest towards 2025-2030 and in individual countries this would be even higher. Gas share in world energy demand peaks in 2040.

A political framework, along with appropriate international institutions to encourage stability, global collaboration and multilateralism could promote solutions to regional conflicts and could be a critical trait of this scenario.

Fossil Fuel Based Technologies for Power Generation

A significant efficiency improvement in energy transformation and use processes would be required in order to allow a reduction in the share of fossil fuel sources in the energy base while energy service demand increases. This would be particularly important in fossil-fuelled power generating technologies, where current average efficiency levels for conventional plants remains below 40%. However, technologies already exist that substantially improve these efficiencies. New gas turbines already have better performances. Cogeneration has very high overall efficiencies. Supercritical pulverised coal plants can presently reach 47% efficiencies and ultra-supercritical plants can do still better. Gas combined cycles can go beyond 50% efficiencies. Integrated gasification combined cycles could allow similar performances using coal as a fuel and stationary fuel cells using hydrogen, natural gas or any gasified fossil fuel would have performances around 60% and better.

Again, however, increasing the penetration of these technologies in the market and stimulating further technological improvements would require substantial policy efforts, as well as sustained growth of the economy. Some of the policies that favour non-carbon emitting technologies (like CO_2/carbon taxes or ceilings to carbon emissions) would clearly boost the development and adoption of low or zero carbon technologies and penalise the least efficient fossil fuel based ones, particularly some of the coal based technologies (although the latter would have to improve their performance significantly just to survive). At the beginning much of the reduction in coal

use would have to be offset by an increase in gas-fuelled generation. Gas use in power generation also would increase due to several other factors, including the diffusion of distributed generation and of co-generation of power and heat or steam. Distributed generation would grow, especially in the residential and commercial sector, with a likely expansion in the use of mini and micro-turbines, as well as Stirling cycles and fuel cells. While significant gains in efficiency are already possible with today's advances, still further improvements would be facilitated through the further development in a number of enabling technologies and new materials.

Another general trend, including in developing countries, would involve the tightening of SO_x, NO_x and particulate abatement standards. This would erode part of the efficiency improvement even in some of the best performing coal-fuelled plants, thus reducing their competitiveness. At a later stage the need to separate and capture part of the CO_2 emitted by fossil-fuelled plants would further aggravate the problem as these additional processes have significant energy costs. Hence in the future producing more electricity from the same amount of fossil fuels (and especially from coal) may not be simple; in part as a consequence, fossil fuel use would slowly decline in power generation. Depending on the level of the implicit or explicit price on carbon or criteria pollutant emission standards, a reduction in coal use like the one envisaged by the SD Vision scenario by 2050 would no doubt take place. At the same time, technological improvement in power generation would be continuously stimulated, counteracting in part the increase in power generation cost due to pollution abatement regulation. Furthermore, system cost increases that could not be offset by technology improvements in power generation might still be offset by increased efficiency in electricity end-use stimulated by higher prices.

Energy End Use

Improvement of fossil fuel based technologies would be needed in all energy end-use sectors: industry, residential, commercial and transport. In particular, in the latter three, the existing potential for energy efficiency improvement needs to be aggressively tapped. The considerations regarding the trends illustrated by table 3.1, concerning the more aggregate concept of energy intensity, while providing an idea of the efforts necessary, at the same time confirms the feasibility of attaining the targets of the SD Vision scenario. Consider by sector what type of measures could be taken.

The Industrial Sector

Attention to the bottom line and to the price signals given by the market puts industry in a better position to react to a changing environment. To be effective, a successful climate and energy policy in this sector needs to send steady signals. While standards may play a role in promoting energy efficiency or reducing polluting emissions, reducing use of carbon based fuels is probably better done through cap and trade schemes, through taxes or through other economic incentives. These, combined with the elimination of harmful subsidies, should induce enough technological change and process innovation to achieve the goals.

The Residential/Commercial Sector

In the residential and commercial sector there is significant scope for energy efficiency improvement. The efficiency of boilers, heating systems and of stoves would have to increase further. Greater diffusion of CHP production, favoured by the recent wave of market liberalisation, in the services sector would help reduce overall energy requirements. But at least initially, the already strong economic advantages of CHP would be further helped by carbon mitigation policies. A substantial share of the residential and commercial market demand could be covered by highly efficient stationary fuel cells. More efficient building design and the integration of solar heating and PV in buildings could also substantially cut heating and cooling needs otherwise met by fossil fuels. In developing countries, more effective ways of transforming biomass into energy services, at the most decentralised level could reduce traditional biomass use for the same amount of energy service produced. A good example of possible progress might be a second generation of "improved stoves". Provided improvements focus on the combustion conditions as much as the heat transfers (REWDP, 2000), these changes may simultaneously help reduce the detrimental health effects of in-door air pollution and the possible effects of biomass overuse on deforestation and desertification, finally reducing the daily workload (mostly for women) to collect the biomass.

Electric and non-electric appliances could be made much more efficient too. This type of development would have to be actively pursued through policies such as efficiency standards (both in building codes and for the energy performance of electric appliances and lighting devices), providing tax incentives or preferential terms in loans for upgrading the energy performance of buildings, eliminating perverse subsidies (i.e. those that encourage energy waste). Norms and standards could be phased in

gradually and continuously tightened with the involvement of both concerned industries and consumer organisations. Also, even in a world in which environmental awareness is already in the mainstream of consumer attitudes, people should be continuously informed and kept up to date about the energy consequences of their habits and lifestyles. The direction of change must be clear and sustained over the long term.

The Transport Sector

In the transport sector enormous efficiency improvements can be extracted even from the internal combustion engine, not to mention continuously improving diesel engines (IEA, 2001b). Hybrid vehicles (using electric storage and conventional engines) would also dramatically cut energy consumption. Fuel cell vehicles, using hydrogen, bio fuels or fossil fuels would have rather high efficiencies too. The future described in this SD Vision scenario assumes a continued variety of transport technologies – with a much more diversified fuel mix than seen at present. While later in the scenario horizon a growing portion of fossil fuels or biomass would be transformed into hydrogen and used in fuel cell powered cars, an important fraction would be still used as liquid fuels (diesel oil, gasoline, synfuels from coal, bio fuels) and used in advanced ICEs, diesel and hybrid vehicles.

For the first two decades of the period considered, increased experimentation by the automotive industries with different engine concepts and different fuels must be encouraged, so that different approaches can be tried and tested and a clear set of winning technologies can emerge. By 2025, it should become clear what type(s) of technology and fuel(s) is (are) likely to dominate the new transport market – and only at that point it will become apparent whether a totally new infrastructure will need to be created to support that technology or whether adjustments to existing infrastructure will suffice.

Fuel cell technologies for transport would, at early stages, use carbon-based fuels either directly (with a reformer) or indirectly (hydrogen). For the latter, efficient ways to concentrate hydrogen, to increase its energy density, and to store it for fairly long periods (days or months) would be needed.

Some of the bottlenecks to the adoption of challenger technologies in the transport sector are already clear. For example, for electric vehicles, the uncertainty lies in whether electricity will be supplied by batteries or produced on board in a fuel cell powered by hydrogen. Research work on electricity storage in on-board batteries would be necessary to increase the

energy density of battery packs, so as to give electric vehicles an operative range comparable at least to that of present day gasoline cars.

In general, new technologies could be nurtured in niche markets, and the winner is likely to be determined based on the speed at which costs decline for that technology and on the comparative simplicity and convenience of its use. Of course various types of hybrid solutions could emerge. It is also possible that certain technologies would prove better suited to an urban environment and others for long-haul intercity transport.

Advanced technology hedging strategies must be accompanied by a parallel strategy for conventional transport technologies. Fuel efficiency standards would likely be needed everywhere (first in developed countries and later in developing countries) and periodically tightened to achieve better performances. Energy taxes (or alternatively externality taxes) could be used especially on fuels of fossil origin, in combination with efficiency standards, in order to reduce the rebound effect. But a more comprehensive approach to the transport sector may also be desirable, as dependence on oil as a fuel and increasing GHG emissions are only two of transport-related problems. The health impacts of polluting emissions from transport vehicles are very serious and increase with population in urban environments. Traffic congestion (and parking space limits) increases the time spent commuting; noise pollution is a growing nuisance and possible health hazard; occupancy of public spaces by cars restricts other activities. In urban environments the problem of mobility could be addressed through appropriate public transport planning and development, which would reduce the amount of resources used (energy, space, time) and of pollutants emitted. While system planning is key to finding and integrating good solutions, new and more efficient public transport technologies are needed too, in order to significantly decrease transport energy needs and polluting emissions. However, a more flexible set of solutions to transport services may become available thanks to the diffusion of information and communication technologies (ICT).

Air transport deserves a separate discussion. This segment of energy demand has seen the most rapid increase of any part of the transport sector over the last two decades. Increasing incomes make this form of transport more accessible for a growing number of people while simultaneously changes in attitudes and of social standards make long distance travel for tourism and vacation routine for a wider segment of the population. Decreasing the energy demands of this form of transport, and the pollution it originates, without reducing mobility is a challenge that

requires improved load management, much more efficient aircraft technologies and materials, and ultimately innovative engine design and fuels. Hydrogen could be one such fuel, but certainly it will not be viable very soon.

Hydrogen and Hydrogen Infrastructure

The issue of hydrogen versus gas distribution will depend on several elements. One of them, as mentioned earlier, is whether or not an efficient hydrogen storage technology will emerge. Another, at least as critical, and not only for the transport sector, is whether it will be possible to produce hydrogen at lower energy costs than presently achievable. Furthermore, producing hydrogen either from fossil fuels or from renewables and nuclear may have both energy and environmental costs: producing hydrogen from hydrocarbons or gasified coal entails large energy losses that are difficult to reduce with current technology. It also leads to the production of very large amounts of CO_2, which would then need to be captured and stored, at an additional cost. A successful targeted research agenda could focus on developing cheaper separation and capture technologies and on demonstration of safety of long term storage.

Similarly producing hydrogen from water electrolysis using off peak electricity produced by renewables or nuclear may be costly from the energy point of view, and if practiced on a large scale would require the use of significant amounts of water, which may not be readily available everywhere. Other options, such as natural gas steam-reforming using high-temperature solar or nuclear heat, are not fully developed yet, though they could drastically reduce associated CO_2 emissions at a low cost. Other technologies (see IEA, 2003 b, chapter 8) are still at an R&D stage. Certainly a full life-cycle analysis of these alternatives would be helpful even to decide where to focus the massive investments required to develop these technologies.

Carbon Capture and Storage

Carbon capture and geological storage, if available on a large scale, would be an attractive option in the short to medium run, and would definitely make a transition to a non-carbon-based energy system less painful. It certainly seems one of the conditions for a full-blown hydrogen economy in which carbon-based technologies remain in use. For this reason it plays an important role in the SD Vision scenario. However, issues such as leakage rates from underground reservoirs (ocean storage is not

considered here) may prevent the use of this technology as a permanent solution. While underground storage capacity for CO_2 in coal seams, depleted oil and gas reservoirs and deep saline formations is very large, (in the hundreds or thousands of GtC, IEA/WPFF, 2002), and could accommodate at least a hundred years of production at current rates, the technical potential may be offset by cost: the process of CO_2 separation and capture from the various fossil fuels or combustion gas streams may significantly decrease the overall energy efficiency of a fossil-fuelled power plant. The problem connected to the use of this technology is that capturing and storing the carbon has itself an energy cost (energy penalty), and if the energy is provided by fossil sources, for the same amount of final energy produced, adding carbon capture and sequestration would lead to more fossil fuels being burned.

More R&D and continued technology improvement would likely reduce these costs – and in some cases, such as enhanced oil recovery (EOR), could even generate increased profits in oil or gas production. However, for large scale capture and storage in electricity generation, these costs would not be negligible, especially when transport costs are added. Furthermore, CO_2 transport and storage would create some formidable logistic problems, as fossil fuels are not necessarily used close to their extraction points. The dispersion of some of these uses complicates the matter further. One alternative would be to strip the fossil fuels of their carbon during the production of hydrogen, and to store the carbon at the point of production while distributing the hydrogen by pipeline. On a global scale, with much of the oil and gas already being moved across borders through pipeline, any vision of the future for the coming 50 years seems to be full of promise for the pipeline industry.

Conclusions

This exercise of constructing a normative scenario for 2050 based on a set of desirable energy and environmental attributes provides a useful tool to focus attention on actions that must be taken and conditions that must be created at certain points in time in order to achieve the scenario goals. The point of departure for this type of work, a vision of the future that is considered desirable, rather than a future inexorably imposed upon us by the inertia of the system, represents a critical change of perspective.

While both still preliminary and somewhat arbitrary in terms of goals set, this analysis has forced us to ask some questions, recognise uncertainties, and identify bottlenecks and priority areas of research and technological development. At this stage this exercise is intended for demonstration purposes. A more systematic and more detailed approach could provide a finer set of warnings, policy recommendations and technology development roadmap than the one produced here. In this perspective the goals should be thoroughly discussed and if possible set in a consensual way.

As this scenario suggests, it is possible to achieve, simultaneously, stringent goals for energy security, climate mitigation, and energy access, if our societies accept the inevitable, but not necessarily huge costs, and address the socio-economic implications. The policy tools are already available – although they must be applied at levels considerably more stringent than heretofore. The changes in the fuel mix, while significant, are within the range of shifts seen in the past – although earlier changes have been not as extensive or as cross-cutting. Current technologies are in many cases adequate to the task – and where new technologies are needed, they are in many cases already at the stage of pre-commercial development. But a vision of the world like the one outlined by the SD Vision scenario can be implemented, and while to achieve it will require long-term sustained efforts, the cost (as indicated by the IPCC work quoted on page 124) need not be prohibitive. Nevertheless, while long term cost assumptions are backed by various modelling exercises, it is clear that a high level of uncertainty remains both over cost levels and their distribution across economic sectors. Such uncertainties are likely to remain controversial and raise, both within and between countries, a number of social and economic issues which will need to be addressed.

This scenario has also allowed us to take a closer look at some difficulties and cross-cutting issues. One critical element is the importance of maintaining sustained economic growth to facilitate the attainment of the stated goals. Economic growth and technological change interact in a complex manner, in a sort of virtuous circle that could be essential to advance in a direction more friendly to the environment. It is therefore important to simultaneously encourage economic growth and the development of environmentally benign technologies. To achieve these goal policies need to work as much as possible with market forces.

A second conclusion of the scenario is that unless a balanced portfolio of strategies is used in pursuing specific goals of energy security, environmental protection or climate change mitigation, some perverse

effects could result. The scenario analysis clearly outlines a number of these risks. For example, there is a clear risk of increasing the world's dependence on natural gas – and a concomitant increase in security of supply risks with respect to this source – if we seek too rapidly to limit dependence on oil. Another case is the risk of pursuing climate change goals through technological paths that lead to a worsening of the problem. This could happen if, to solve the problem of CO_2 emission reduction in transport or in other sector we resort to massive scale hydrogen production from fossil fuels: hydrogen could well be "another expensive way to burn more coal". As for the case of air pollutant abatement technologies, carbon capture and sequestration could lead to higher energy use, and possibly to higher carbon emissions.

Significant undesirable environmental and security impacts for future generations could also result from massive production of energy from nuclear fission technologies at a scale like the one envisaged by this scenario. These risks need to be carefully examined and kept under control both through technological approaches and political approaches.

Perhaps the only "risk-free" option is efficiency improvements in energy production and use – which we thus conclude should be promoted as much as possible, while seeking to limit the rebound effects from efficiency gains.

Ultimately, the use of the normative scenario process lies as much in the issues it requires us to confront as in the precise details that it generates. Obviously, the future will not look like the one set forth in this discussion: other priorities will intercede, and national conditions and circumstances will dictate the specifics of the energy policies that may be adopted. But such a process of iterating around scenarios can provide valuable guidance as to what we must do – collectively and individually – to achieve policy goals such as these.

CONCLUSIONS

This volume has sought to make the case, both through a review of past practice and through the development of new scenarios, that an approach to exploring the future can make important practical use of scenarios. It is clear that the future is not simply something already predetermined that we must accept blindly; rather, it is open and to a large extent determined by the course of actions we decide to take. For this reason we need to look at the future and its uncertainties in an articulated fashion, developing specific tools to consider both how the future might unfold if we do not act – and how we might like the future to unfold if action were to be taken.

Models of the energy-economic system provide one, very useful tool to undertake this assessment. The IEA's World Energy Outlook provides a quantitative example of how that work can be carried forward, building on past trends to describe future outcomes. Unfortunately, in most cases, such models lose their efficacy when projecting present trends more than 20-30 years out – and even in this horizon, modelling groups use story-lines or judgemental parameters to make choices regarding elements such as technology development and changes in economic growth. Yet fundamental and undesirable changes in our system can be predicted if we simply follow Business as Usual or Conventional Wisdom paths. We need tools to examine both the longer term – running at least to 2050, and tools to help choose policy paths that avoid such problematic outcomes.

As demonstrated in chapter 1, one valuable intellectual exercise for looking into an uncertain future involves the development of "scenarios", intended as logical and plausible conjectures about how fundamental drivers will affect global societies, economies, resource use and the environment. The literature review shows a multiplicity of scenarios, conducted at different scales ranging from the national to the global scale, with different time horizons, and with a focus on different strategic issues.

Exploratory scenarios help prepare for events that, without representing a straight-line continuation of past trends, are plausible and entirely possible. They are particularly useful when contemplating potential bifurcations in fundamental drivers for change, especially when hints of such situations can be found in the present. Exploratory scenarios can help a lot to accelerate and calibrate the response to new developments (both

positive and negative), as well as providing a strategic framework for technology development policy.

In contrast to exploratory scenarios, the exercise of constructing a normative scenario has, as its goal, the evolution of a desirable future, rather than a future inexorably imposed upon us by the inertia of the system. It thus represents a critical change of perspective. It provides a useful mechanism to focus attention on several crucial elements: actions that must be taken and conditions that must be created at certain points in time in order to make the scenario possible. The emphasis here is on planning to achieve a certain result rather than on preparedness in responding to uncertain events. The basic attitude in this case is a more proactive one, and policy intervention is a tool of choice.

Building a normative scenario requires the creators to clearly define the desirable characteristics of their future, and to express this future in terms of measurable targets. In the process of developing a scenario, those creating (and using) it must address critical questions, including how to recognise and address uncertainties, how to identify bottlenecks and priority areas for policy action, and how to incorporate elements such as research and technological development into a plausible framework.

An effort to construct such a scenario, building on normative elements of energy security, climate change mitigation and access to energy services was undertaken for this work. This effort must be recognised for what it is: an internally consistent and plausible image of the future that serves to illustrate the process of scenario development, and to outline the kinds of policy choices that such a future might allow. It is intended for demonstration purposes. A different set of analysts would clearly create a different future – even faced with the same set of goals. A different and lengthier assessment could also yield a more finely discriminated set of warnings, policy recommendations and technology development roadmap than that produced here.

Ultimately, the use of such a scenario process lies as much in the issues it requires us to confront as in the precise details that it generates. Obviously, the future will not look exactly like the one envisioned: other priorities will intercede, and national conditions and circumstances will dictate the specifics of the energy policies that may be adopted. But such a process of iterating around scenarios can provide valuable guidance as to what we must do – collectively and individually – to achieve the set policy goals.

Building Useful Scenarios

The interest and success of any scenario exercise rest on its foundations. For Business as Usual forecasting the foundation is given by the quality and accuracy of information on past and present trends. For exploratory scenarios, clarity in the statement of the problem is perhaps the most fundamental criterion. A correct elaboration of the central question being asked is what helps focus on the critical uncertainties for the problem at hand, and correctly identifies the factors that have the greatest impact on the final outcome. Alternative developments in those factors then shape the scenarios, producing different images of the future. In turn, those different images of the future help appreciate the breadth of uncertainty and facilitate a discussion on how to best tailor policies and strategies to be successful in coping with such future outcomes. However, one point is plain: in any scenario of this sort, success cannot be defined other than with respect to the initial question or problem. Scenarios do not stand in isolation from the questions they are built around, and cannot thus be taken out of that context to answer other questions of future policy.

Normative scenarios follow a similar path. However, in this case a strong foundation requires not only clarity related to the question being asked, but also clarity and consensus around the broad goals that a successful outcome would entail. While the importance of both elements is self-evident, it needs not translate into extreme accuracy of values chosen as measurable targets. Often the measurable targets represent useful proxies for the more complex concepts that constitute the objectives (e.g. security of supply, environmental sustainability, and so on). It is the latter that must be as clear as possible, as they will shape both quantitative and qualitative aspects of the scenario. The consensus around the objectives is paramount in an approach that relies on policy action and hence on political will to move towards the goal.

This reminder is important because developing a lucid statement of a problem and a clear and consensual formulation of objectives are non-trivial tasks: in fact they might be the most difficult undertaking of the entire scenario development exercise. The reason for this is that in the real world most of the problems we deal with involve a plurality of stakeholders. While the difficulty of the task is sensibly reduced for decisions involving ourselves and our immediate entourage, or a small business enterprise, dealing with sensitive issues like energy, sustainable development, or climate change mitigation concerns a much broader

community. The stakeholders include the world's citizens, their governments, businesses, and NGOs.

For an organisation like the IEA, representing some 26 member countries and conscious too of the broader implications of its policy recommendations, the development of any scenario is fraught with difficulty and potential conflict. For the specific scenario exercises carried out here the task has been enormously simplified by the existence of a set of shared goals of the IEA member countries, already included in various carefully worded IEA documents. By basing scenarios on these goals, it is possible to get a sense of possible areas where member governments might agree on outcomes. However, the scenarios constructed in the analysis presented here did not involve the extensive public consultations with multiple stakeholders that a full, consensual process would do. Furthermore, the shared goals are quite broad and provide considerable latitude for interpretation: going to a higher level of specificity may turn out to be more complicated. As a result, the work in the development of these scenarios should be regarded exclusively as a demonstration of what might be done – and not as a statement of what the IEA member governments would have agreed if such a scenario process were to be undertaken.

One of the conclusions that may thus be drawn relates to how the IEA might carry out such work in the future. The process of a wider consultative approach and involvement of experts from all IEA member countries would be central to such an effort. While likely difficult – and perhaps at times contentious, such an effort would surely bring still further policy relevant results to a critical area of international discourse.

Drawing out Insights: what does the Literature Tell us?

A substantial body of literature is available reporting on numerous and varied scenarios in the area of environment and energy. Those considered in this text look both at the 2050 and the 2100 horizon. They are mostly narrative scenarios, although a large number of them have been at least minimally quantified. The majority of scenarios described are of the explorative type; a significant number of them have been developed for strategic analysis and hence are used to test what strategies would be more robust or more resilient, with respect to a stated objective, in different worlds. A few scenarios have a normative component.

This subset of the wider scenario literature was included in this analysis for several reasons, but primarily because these scenarios included drivers specifically related to the issues central to the international debate on energy and environment. Ultimate drivers constitute the main uncertainties and usually represent the axes along which the scenarios are developed. In many cases these drivers refer to the human element: they represent "human responses", "socio-cultural values and priorities", "desires and aspirations", "attitudes towards the environment". Another category of drivers concerns "resources" and "long-term ecological processes" most of which lie entirely outside the human domain and control. A third fundamental driver is technology, an element typically within the human domain but still highly dependent on unpredictable and often random factors. Among the proximate or derived drivers we have found elements like population dynamics, level of economic activity (GDP), technological choice, which are found more often as exogenous variables in modelled scenarios.

While we have picked these scenarios because of their relationship to the energy and environment issues we sought to analyse, it is useful to assess whether, in fact, these drivers do lie at the root of the future evolution of these issues. The simple answer is: yes. This insight was confirmed by others. During a seminar on long-term scenarios organised in October 2001 by the IEA, energy analysts and scenario experts engaged in an attempt to define a list and a ranking of main drivers for the future of climate and energy policy. Drivers discussed on that occasion are almost the same as those emerging from this literature review with technology and technology-related factors ranking highest, followed by a cluster that included values, lifestyle, and behavioural elements particularly of certain actors. Third was income and income distribution, followed by population.

Scenarios reviewed demonstrate a number of limitations. For example, most global scenarios failed to explicitly discuss the technologies that are strategic to our societies and that might ferry us to sustainable futures (which technologies do we need and how do we develop them; where should we concentrate our research efforts and budgets?). It is not clear that such a focus is impossible at the global scale. Thus, it may be possible to extend the work undertaken by national level scenarios – which analysed clusters of priority technologies that need to be developed, and provided a sort of technological road-map for the future. The usefulness of forward thinking of this type cannot be overstressed in times of limited money and a near-term focus of R&D budgets.

Another incompletely sketched aspect of the scenarios examined is that of bottlenecks in fossil fuel supplies that might well materialise in the coming

decades. Some scenarios contemplate worlds where oil or gas supplies become increasingly insecure due to closing markets and regional conflicts. These scenarios tend to favour coal as a refuge from energy supply shocks, with predictable environmental consequences. Most scenarios agree that there is no immediate threat of shortage of oil and gas reserves (although the situation may change). Yet it is clear that the increasing dependence of developed and developing countries alike on oil reserves that are geographically concentrated in relatively troubled areas of the world presents risks.

Additionally, the scenarios analysed are, for the most part, policy-neutral (that is, they do not assume any specific policies directed at reducing environmental impacts or security concerns). Those that actually envisage (either in a normative light or in an explorative context) a sustainable world or simply one where GHG emission concentration is stabilised at a "safe" level, require either technological breakthroughs or truly gigantic efforts from society in terms of political will and/or epochal changes in consumer preference. In exploratory scenarios this type of factor can be assumed among the drivers, but it is only in normative scenarios that they can be fully appreciated. Again, the lesson seems clear: a mix of approaches, including explorative and normative scenarios must be part of the policy toolkit.

As for the types of worlds described in exploratory scenarios, both negative or undesirable scenarios and environmentally benign scenarios are found in the literature. The outcomes seem to depend mainly on the direction taken by prevailing values, level of technological innovation, and openness of markets. The lesson here is also plain: choice in policies – but also the development of random and uncontrolled events – can have enormous implications for the overall tenor of our global future. The value of considering the gloomy paths is that we will not be unprepared to meet those challenges; the advantage of considering the unrealistic options is that we may isolate the key factors that could help move us in that more welcoming direction.

Developing a New Scenario: the Explorative Approach

Our review makes clear that existing scenarios, while shedding light on a number of critical energy questions, did not adequately address the policy issues that must be confronted and that a number of key uncertainties could usefully be further explored through new scenario work. For us, the questions and uncertainties that still seemed inadequately addressed are

for the most part related to energy security, environmental damage and technological development. And, from this conclusion emerged the interest in developing new scenarios with the specific purpose of exploring possible energy futures for energy and the environment over the coming 50 years.

Given the multiplicity of possible interests and outcomes, it was clear that exploring a family of scenarios rather than developing a single alternative would be most appropriate. The scenarios were thus built around two main drivers that appear as fundamental forces in shaping the future for energy and environment. These are the speed of technological change especially in the energy sector (varying from slow to fast) and the attitudes of people at large towards the global environment (varying from unconcerned to concerned), particularly with respect to climate change issues. Creating a simplified matrix of these variables provided four outcomes, although only three were characterised in much detail (the fourth, low security and low environmental concern, was dismissed). The resulting three storylines represented three rather extreme views of the future world, covering a wide range of cases for the chosen variables. They do provide a way to clarify logical chains of events and possible consequences. All three scenarios have elements of plausibility – although, as with any specific scenario, they cannot be said to represent what *will* occur. In fact, it seems much more likely that the future world will be some combination of the three cases.

The three scenarios do allows us to think about the future in a systematic way, to identify potential threats and opportunities lying ahead, thus providing us with useful insights for planning. Clearly, however, there is an element of oversimplification in the scenario process that must be kept in mind while deriving conclusions.

What conclusions can we draw? With respect to the sustainability of the futures they portray, two of the scenarios illustrated exhibit some obviously undesirable traits. In Scenario 1 (*Clean but not Sparkling*), notwithstanding attitudes of concern towards the environment, the goal of creating the conditions for long-term sustainability is missed for lack of appropriate technologies. In Scenario 2 (*Dynamic but careless*) increasing demand pressure on scarce fossil resources, poses substantial risks from the point of view of global security. Furthermore, the environment is threatened through significant increases in greenhouse gas emissions. However, the dynamic scenario produces a wider array of technology options – and these, in turn lead to the potential for a more sustainable future later on. The third scenario (*Bright skies*) meets the conditions for long-term

sustainability, and presents very low risks from the point of view of security of supply.

Although for different reasons, all three scenarios indicate that, for the coming fifty years, we may expect a substantial growth of gas demand worldwide: gas should be overtaking coal and then oil at some point during that period. In consideration of such growth in demand, gas prices would increase unless exploration, extraction and transport costs decrease fast enough to keep pace over time. This suggests that finding gas in the quantities needed and then delivering it to the consumption markets will be a challenge for the coming decades. Oil demand would also increase, although not as fast as gas demand, and not at the same pace in the three scenarios considered. In at least one of the scenarios, geopolitical risks associated with the location of known oil deposits would provoke recurring crises in the oil markets and price spikes.

All three scenarios assume continuing economic development over the coming fifty years in developing countries (although at different speeds), leading to energy consumption patterns increasingly similar to those of the developed societies. Two scenarios (*Clean but not sparkling*, and *Bright skies*) show a certain measure of convergence of average incomes between OECD and developing countries, while income gaps could actually been maintained in the *Dynamic but careless* scenario.

The three stories indicate that for long-term sustainability it is critical to ensure robust dynamics in technological improvement but that unless there is a fundamental change in values and attitudes towards the global environment, technology alone cannot be trusted to supply the entirety of the solutions. Values and attitudes are what give direction to technological change and, vice versa, the direction of technological change reflects the system of values of a society. The scenarios thus show that policy can have a role not only in directing research and technology development towards the attainment of specific social objectives but also in favouring (or hampering) successful and rapid technological change. However, while designing intelligent policies that increase the chances of successful technological development is something that can be done by good policy analysts, implementing the policies requires political will, and that ultimately depends on social values and priorities: an altogether much more difficult variable to change.

Concerning technology, the three scenarios present clear differences with respect to the technologies that are likely to emerge in these three different contexts:

- the *Clean but not sparkling* scenario, besides stressing spartan behaviour on the part of energy users, concentrates on more energy-efficient and cleaner end-use technologies, on fuel switching and on renewable energy technologies. It later reconsiders zero carbon emitting technologies like nuclear;
- the *Dynamic but careless* scenario focuses initially on fossil fuel based technologies but later, in order to mitigate security of supply concerns develops other alternatives, like nuclear and hydrogen;
- the *Bright skies* scenario develops the entire range of options early, choosing both near-term focus on efficiency and a longer-term focus on zero carbon emitting technologies for medium to large-scale energy production.

A more detailed look at the technological aspects of these story-lines allows some additional insights to be drawn, particularly related to security of energy supply and environmental sustainability. Certain technology areas are critical to all three scenarios and thus appear most robust in different situations. On the energy supply side these include:

- energy efficiency improvement (EEI) in supply technologies;
- advanced gas technologies in power generation: combined cycle gas turbines. Gas transport, storage and liquefaction/re-gasification technologies;
- cleaner coal technologies (Pulverised coal, FBCC, PC supercritical and PFBC). Technologies for criteria pollutants abatement (SO_x, NO_x, PM);
- combined heat and power production. Micro-generation (gas). Fuel cell power plants for power or CHP production;
- nuclear technologies; life extension and safety; new reactor concepts;
- power generation from renewable sources: solar PV, high temperature solar thermal, wind, biomass, and hydro;
- technologies for hydrogen production (from coal, gas, nuclear or biological agents), transport and long-term storage;
- power storage technologies;
- carbon capture and storage for large-scale use;
- fusion.

On the energy demand side robust actions include:

- energy efficiency improvement and conservation in all demand sectors; more efficient appliances, wider use of ICT to optimise performance;
- low energy- and material-intensive manufacturing processes and services;
- passive heating and cooling technologies & architectures in buildings. Building management systems;
- fuel efficiency improvement in conventional vehicles. Bio fuels. LPG and methane;
- hybrid vehicles. Electric vehicles;
- fuel cell (gas or hydrogen fuelled) cars. Hydrogen storage technologies;
- mass transit systems. Advanced public transport systems;
- fuel cells for direct use of power.

Development and diffusion of these technologies at acceptable costs thus appear desirable to contribute to overall improvement in the efficiency of energy production and use or to the reduction of GHG emissions, or to both. In some cases, they could also help mitigate security of supply risks.

Some technologies however appear mainly in the *Dynamic but careless* scenario owing to its strong focus on fossil fuels and limited interest in reducing CO_2 emissions. These technologies (oil and gas, extraction and transport technologies; oil shales and tar sands treatment technologies; enhanced oil recovery technologies; coal liquefaction and gasification technologies) while helpful in reducing security of supply risks, might result in faster production of greenhouse gases should they acquire a large market share.

Moving to Policy Intervention: the SD Vision Scenario

The *Clean but not sparkling, Dynamic but careless*, and *Bright skies* scenarios were built for the purpose of exploring a range of outcomes and analysing their implications for strategic decision-making. However, it seems clear that relying solely on luck to reach a desirable long-term outcome is too uncertain a prospect. In two of these three scenarios, much of the next 30-50 years looks rather grim. Policy intervention, in which

governments, individuals, companies and civil society seek to be proactive, may be needed to ameliorate the worst effects – and hopefully to promote the appearance of a more palatable future.

The development of such a scenario is clearly a step along the path from understanding the future to acting to change it for the better.

The "normative" scenario, called the Sustainable development vision Scenario, outlines a "desirable" vision of the future expressed by specific characteristics or quantitative targets to be reached. Guidance regarding the drivers in the area of energy and sustainable development are taken (albeit loosely) from the IEA Shared Goals, again focusing on energy security and climate change mitigation, but in addition, adding a component related to the provision of energy services to those currently without access.

To construct the scenario, these three general goals, to be reached by 2050, were translated into specific targets:

- reducing dependence from oil in the transport sector to 40% or less;
- increasing the share of non-carbon emitting sources (including fossil fuel use with carbon capture and storage) in total primary energy supply to at least 60%; and
- supplying electricity to at lest 95% of world population.

Borrowing from a scenario developed at the International Institute for Applied Systems Analysis (IIASA) for the Intergovernmental Panel on Climate Change (IPCC), a description and a broad quantitative framework for this normative scenario to 2050 was also constructed.

The resulting scenario was used as a point of departure to consider the conditions that must be fulfilled or the measures needed at different stages along the path to implement these goals, as well as to analyse risks and difficulties that may arise along the way. This approach represented a critical change of perspective. The purpose of the exercise was to illustrate, in concrete terms, how to develop such scenarios, and to stimulate discussion and thinking based on the scenario output about the long-term issues emerging at the intersection of energy and environment.

What can we then say? Perhaps most significantly, the discussion developed around this scenario argues that it is possible to achieve, simultaneously, stringent goals for energy security, climate mitigation, and energy access. Thus such stringent goals need not be only aspirational and unachievable. Rather, with policy intervention, they can be met. The policy

tools are already available – although they must be applied in a much more aggressive and sustained way than has been the case in the past 15 years. The changes that would be necessary in the fuel mix, while significant, do not involve quantum leaps and would not be more dramatic than some we have seen in the past (for instance with the nuclear programme). In some areas they would be possible with current technology – and where new technologies are needed, they are in many cases already at the stage of pre-commercial development. Although long-term cost estimates are prone to a high level of uncertainty, existing analysis shows that costs need not be high, and might be reduced if ancillary benefits (for example, of air pollution and human health) are included in the cost analysis. Uncertainties over cost levels and the distribution of costs across the various economic sectors will likely remain controversial and raise, both within and between countries, a number of social and economic issues. Future work could aim at more precisely assessing the costs and benefits, possible distribution and the associated socio-economic impacts of meeting these goals.

Analysis of the normative scenario also confirms the importance of promoting the development of new technologies – and reinforces the message built on the results of the exploratory scenario work with regard to *which* technologies to promote. Here again the message is simple and clear: new technologies have to emerge rapidly, and existing technologies must be further developed to reach the objectives. While specific policy tools were not evaluated during the building of this scenario, other ongoing IEA work does provide clues as to the policy approaches to promote technology development and diffusion: higher or better focussed R&D expenditures, well-structured market incentives and price signals, and more extensive technological collaboration among countries all form part of the mix.

However, while there are positive messages, all is not rosy. This scenario also allows us to visualise some difficulties and issues in a more global and integrated perspective and to identify some critical aspects. Among them, maintaining sustained economic growth to facilitate the attainment of the stated goals is vital. There is a clear and close link between dynamic technological progress and attitudes favourable to protection of the environment. To encourage at the same time economic growth and the development of environmentally benign technologies, policies need to work as much as possible with market forces.

Another element is the need to maintain a balanced portfolio of strategies in pursuing specific goals of energy security, environmental protection or

climate change mitigation. Unless this is done, we may again fall prey to perverse effects: creating other dependencies on scarce energy resources or resorting to energy technologies that indirectly cause an increase in GHG emissions or in the creation of more hazardous waste. For example, while natural gas has the potential to be a transition fuel on the road to a very low carbon world, the pressure on gas demand could generate other supply vulnerability problems. Likewise, using coal to produce hydrogen, unless accompanied by adequate technologies for carbon capture and storage, could make hydrogen a very "dirty" fuel. For this reason efficiency improvements in energy production and use should be promoted as much as possible, while trying to limit the rebound effects of this added efficiency.

Policy conclusions may be drawn here too. For example, subjecting new technologies (even when they are still at a conceptual stage) to a continuous analysis of their environmental impacts, from a cradle-to-grave perspective, is extremely important especially if the perspective of technology policy is seen together with environmental and energy policy.

Ultimately, the usefulness of the scenario development process lies as much in the issues it requires us to confront as in the precise details that it generates. It is the basis for sensible planning, even when we may have to change plans later as situations evolve and new information becomes available. While we can say – with certainty – that the world of 50 years from now will not look like our scenario, the process of scenario development can provide valuable guidance as to what we must do – collectively and individually – to achieve policy goals such as a sustainable energy and environment future.

Where do we go from here?

The process outlined here demonstrates what has been done by others in the global community seeking to better understand the future through the use of scenarios, and takes a first step at carrying it forward using IEA goals as the basis for considering a more favourable outcome. The exploratory scenarios constructed and reviewed in Chapter 2, as well as the normative scenario developed in Chapter 3 provide a basis for strategic discussion. However, to be more fully exploited, we must now ask which strategy, in each scenario, would likely be successful in reaching the objectives we seek, and offsetting the worst of the damage. From this, we can then begin to isolate and hopefully, take policy action to adopt those

strategies, including ones to promote appropriate technologies, that are robust across all scenarios considered.

Full quantification of scenarios is not, *per se*, necessary, and can be a costly exercise (especially because these types of scenario usually come in sets). Story-line scenarios, even when developed only in qualitative terms, offer the necessary elements to ground much of the strategic discussion. Furthermore, quantification risks shifting the focus of discussion to specific numbers (rather inappropriate considering the speculative nature of this exercise), preventing the exploration of more critical qualitative aspects.

However, for energy and environment issues like the ones discussed here, an approximate quantification of such elements as for instance energy demand and energy service demand, or GHG emissions, might turn out to be useful, and provide additional policy information. The problem then becomes one of finding a suitable model capable of illustrating the story-lines already drafted and of finding suitable proxies for whatever qualitative variables or drivers are considered.

Quantification may be more interesting for a scenario of the normative type than for exploratory cases. As shown by our exercise, it helps the visualising at least approximately of some of the magnitudes involved and appreciation of the difficulty of the tasks to achieve the desired outcome. Depending on the modelling approach used, quantification may provide useful indications about the economic costs involved in achieving the targets. Or it may indicate the relative costs and benefits of implementing alternative policies to achieve the same objective.

But the main utility of the normative scenario is as a planning tool. It concentrates minds on final objectives, short-, intermediate- and longer-term milestones, necessary steps to facilitate the achievement of each of those intermediate goals. It may help draft realistic roadmaps for technology development and deployment. It encourages forward thinking and early research for solutions to problems that are likely to emerge down the road to the desired outcome.

Ultimately, if the international community is to be successful at meeting the goals of energy security while protecting the global environment and providing people everywhere with full access to energy services, we will need to press into service all available tools. The scenario process is one such tool – and an effective one. However, it remains only a tool. More critical – and ultimately, the truly important tool, is the development of political will to act on conclusions, which will always remain the key to a more sustainable energy future.

APPENDIX I: SCENARIOS FROM THE LITERATURE REVIEWED

Global (World) Scenarios

Shell's Scenarios

The first of the 2001 Shell scenarios is called **Dynamics as Usual**. It is based essentially on a continuation of past dynamics: demand for cleaner energy, gradual shift from high to low carbon fuels and towards electricity as energy carrier. It describes a world shaped by social priorities for clean, secure and ultimately sustainable energy, but also of conflicting interests, intense competition and a wide array of maturing and emerging technologies, leading to a highly diversified energy system. This scenario sees, on one hand, rapid economic growth in major developing countries like China with explosive growth in energy demand for transport, electricity and related infrastructure, and on the other, little extra increase in energy demand to support economic growth in OECD countries. Progress in communication and materials technologies allows a significant decrease in energy and materials intensity of income world-wide. Public concerns for health, environmental quality and climate, though stronger in developed countries, push companies to develop a wider range of clean fuel and technology options. Concern for security, on the other hand, stimulates greater energy efficiency, rejuvenating technologies like the internal combustion engine, with its hybrid variant, and slashing fuel consumption to one third of present requirements for the same service. These developments are able to contain oil price growth until 2015, after which increasing demand in developing countries strengthens it again. Fuel cell vehicles, as well as stationary applications are introduced but fail to take off.

New power generation is mostly gas-fuelled wherever gas is available: the dash for gas is spurred by the superior economic and environmental characteristics of the combined-cycle gas turbines, which replace many old coal-fired plants. Gas gains market share even in China and Latin America, supported by expansion and integration of gas grids and increased LNG trade. By 2010 gas overtakes coal and by 2020 challenges oil as the dominant source of primary energy, amid growing unease about supply security. Nuclear capacity is maintained but loses market shares in the OECD and grows only slightly in developing countries.

Renewable energy sources experience a boom in the first two decades especially in OECD countries, pushed by public concern for health, climate, and supply security, as well as government support and green energy schemes. Yearly growth rates exceed 10% overall for renewables, and 20% for solar PV and wind. By 2020, about 20% of electricity in many OECD countries is supplied by renewables. But then their market penetration reaches a plateau, due to such factors as increasing siting difficulties and environmental problems, continuing high costs, lack of progress in power storage technologies, and stagnant electricity demand in the OECD. In developing countries renewables start taking off after 2010, but they do not fully compete with low cost conventional sources or with energy efficiency measures.

Around 2025 governments face tough choices about energy supply mixes. No technology/fuel option stands out as a clear winner especially vis-à-vis increasingly stringent environmental standards. Even new nuclear generation stalls. Later, renewables make a strong comeback. Growing scarcity of oil and further advances in biotechnologies bring a smooth transition to liquid bio fuels for transport, now the focus of much biomass production. Progress in materials, electrical controls and storage technologies enable a new generation of renewable technologies, notably in solar energy, and by 2050 renewables supply one third of world primary energy.

The Spirit of the Coming Age describes "a world in which superior ways of meeting energy needs are developed to meet consumer preferences" (Shell International, 2001). This is a scenario of revolutionary rather than evolutionary developments as in the previous case. However, the revolution takes place mostly at the fringe of the energy system while maintaining continuity with established consumer preferences such as that for freedom of mobility, flexibility, convenience, and cleanliness. Fuel cell powered vehicles respond to all these needs. However the constraint is fuel infrastructure. Initially uncertainty exists as to the preferred fuel source: natural gas, methanol, or direct hydrogen. Soon, however the auto industry develops a new "fuel in a box". The fuel itself can be made from oil, natural gas or biomass. As soon as a certain energy density threshold is crossed (12 litres of fuel sufficient for 400 Km) and the fuel can be packaged in compact, easy-to-distribute containers, a host of distribution channels (supermarkets, vending machines, and so on) are readily available. This frees the fuel cell car from the constraint of the distribution network and makes the construction of dedicated infrastructure unnecessary, which turns out to be particularly acceptable in developing countries.

The development and the initial "technology learning" for the fuel cell takes place in stationary applications for power generation, particularly in niche markets where highly reliable power without voltage fluctuations or outages is needed. This development is favoured by the existence of natural gas distribution networks. By 2005, as soon as fuel cell system manufacturing costs go below $500/kW, a large market for transport applications starts opening up. By 2025 25% of the OECD vehicle fleet and 50% of all new cars is powered by fuel cells; the latter figure is close to 25% for car sales in developing countries. However, development also continues in the residential sector, with the possibility of producing – and trading surpluses of – electricity and hot water (as a by-product of fuel cell heat). Both transport and stationary applications of fuel cells benefit from advances in materials technologies such as carbon nano-tubes and later carbon nano-fibres as ultimate hydrogen storage medium.

To satisfy rapidly growing demand for gas and hydrogen, besides advances in natural gas exploration and extraction, progress in low-cost and unobtrusive in-situ extraction of methane and hydrogen from coal and oil shales is necessary. Furthermore, carbon dioxide sequestration becomes feasible. Availability of these technologies frees many countries (most notably China) from dependence on foreign oil. The transition to a hydrogen world is well in progress before oil becomes scarce: in fact as fuel cells start dominating the transport market, oil prices remain weak.

Renewable energy progresses steadily but slowly until 2025. Photovoltaics enjoy initial successes within rural communities in developing countries. But urbanisation trends and growing electricity needs play in favour of fuel cells. In industrial countries, notwithstanding initial government support, renewables cannot bridge the cost competitiveness gap with other developing technologies.

Progress in fuel cells in various markets steadily increases demand for hydrogen, which is now produced from fossil fuels, with CO_2 separated and disposed of at the source. Carbon sequestration grows to from 0.3 billion tonnes in 2025 to 3.6 billion tonnes in 2050 (a quarter of emissions) peaking soon after. After 2030 large-scale renewable and nuclear energy schemes to produce hydrogen by electrolysis become attractive; and while until then hydrogen is transported mainly in gas grids, a dedicated infrastructure becomes necessary.

Stockholm Environment Institute - Global Scenario Group

The **Reference** scenario assumes strong economic growth, mid-range population and development projections and gradual technological change. In this world economic growth has top priority as largely unregulated markets expand internationally. In this world there are countries, groups and businesses which lose out, and others that prosper. Population growth is uneven and there is increasing migration from poor to rich areas. The rich get richer, and although some social strata achieve affluence, poverty persists. In fact income inequality increases. Environmental quality improves in rich countries and deteriorates in poor ones. Social conflict intensifies due to migration pressures, competition for natural resources and environmental deterioration. Other underlying trends in this scenario are: structural shifts in economic activity from industry to services, first in OECD regions, then gradually elsewhere; increasing dematerialization of industrialised economies; technological improvement gradually leading to more efficient use of energy and water. Despite these phenomena, pressure on resources and the environment increases dramatically as the scale of human activity becomes overwhelming: one indicator is the substantial increase in CO_2 emissions. There are strong indications that this scenario is neither sustainable nor desirable as environmental pressures exceed the assimilative capacity of the system and as social tensions mount. Unfavourable climate alterations would further complicate matters (Gallopin et al., 1997).

The **Policy Reform** scenario is still growth-oriented but acknowledges the risks posed by the Reference scenario and assumes a policy response to counter those threats. These policies would be in particular directed to increase economic growth, increase distributional equity, foster new and more efficient technologies and protect the environment. As a result this scenario would lead to lower levels of social conflict and a healthier environment. It is not clear whether this scenario, without fundamental structural change would offer a plausible pathway to sustainability. Furthermore it calls for very strong political will to initiate and sustain massive policy intervention, and this by itself is a daunting challenge (Gallopin et al., 1997).

This scenario is manifestly normative and its development is illustrated at length in the report "Bending the Curve: Towards Global Sustainability" (Raskin et al., 1998). As it is normative, its development moves from the definition of the objective to a vision of the future that satisfies criteria for global sustainability. The concept of sustainability here is broadly the one

adopted by the Brundtland report to the World Commission on Environment and Development, "Our Common Future", based on the twin requirements of environmental and social/economic sustainability. This concept is translated by the GSG team in a series of sustainability goals that must be globally attained by 2050. These include such environmental goals as stabilizing the climate within safe ecological limits, reducing the flow of materials through the economy, decreasing toxic waste loads to the environment, easing the pressure on freshwater resources and maintaining the integrity of ecosystems. But they also include social goals like the provision of basic human needs such as adequate food, clean drinking water and access to health care and education, reduction of income inequality and decrease in the level of violence and armed conflict. To design and test appropriate policies, these goals need to be translated into quantitative objectives and indicators of progress that set the constraints of the Policy Reform scenario. Through the "back-casting approach" actions and measures necessary to achieve these goals are laid out for each individual goal and indicator. Thus the scenario translates into a series of policies and policy instruments to attain both environmental and social goals as well as in the identification of agents and institutions which might act for change (Raskin et al., 1998).

The **Barbarisation** scenarios explore the possibility of a far grimmer world than that depicted in Conventional Worlds, a situation in which the socio-ecological system veers towards a state of declining physical amenities and erosion of the basis of civilisation. These scenarios are explored with the aim of identifying early warning signs.

The main driving forces in these scenarios include worldwide political and economic changes, growing populations, income inequity and persistent poverty, environmental degradation and technological innovation. In this world, uncertainties exist as to the successful transition to market based economies and to democracy of Russia and Eastern European countries. National governments lose relevance relative to transnational corporations and global market forces; disenchantment with development aid causes a reduction in development assistance to poor countries; absolute poverty increases and so does the gap between rich and poor and resentment on the part of the poor. With rapid population growth in poorer regions, a huge international youth culture emerges, exhibiting similar expectations, consumerist and nihilist attitudes, and frustration at the impossibility of attaining a "MacWorld" lifestyle. These tensions cause waves of (often illegal) immigration to rich countries or, in poor ones, to the more prosperous areas. (Gallopin et al., 1997).

Unchecked expansion of market economies leads to increased industrial activity and rising pollution. Environmental conditions worsen everywhere, especially in poor countries. Increasing urbanisation causes severe stress to local environments and to water resources. Scarcity of freshwater induces conflicts over its allocation. Marine fisheries collapse, causing loss of food resources to billions of people; climate change harms subsistence farming especially in poor countries, causing frequent and severe famine. New diseases emerge and old ones reappear, increasing mortality rates in some areas. Scientific and technical knowledge become an increasingly private commodity, widening the gap between rich and poor and slowing progress on fundamental problems (Gallopin et al., 1997).

Then severe social and military conflicts start to emerge and spread, fostered by growing socio-economic inequity and reduced access to natural resources. Small-scale armed conflicts become common, driven by ethnic or religious differences and conflicts over resources. Civil order breaks down encouraging anarchy in many areas, or diverting significant resources in the name of security and causing a fall in international investment. Regional fragmentation increases. Incessant conflict, chaos, and uncertainty prevent economic development and technological progress (Gallopin et al., 1997).

The reaction of the remaining institutions to this state of affairs constitutes the critical uncertainty shaping the two scenarios of the Barbarisation world. In the **Breakdown** variant, institutions cannot cope with the rising tide of socio-economic chaos; conditions spiral out of control, leading to a general disintegration of social cultural and political institutions, deindustrialisation and the return in many regions to semi-tribal or feudal social structures. This condition could persist for decades before social evolution towards civilisation resumes. In the **Fortress world** institutional response is sufficiently coherent and forceful to restore some order, albeit authoritarian. Regional and international actors are able to muster a sufficiently organised response to protect their interests and to create lasting alliances between them. But these are directed to protect the privileges of the rich and of powerful elites, which retreat to protected enclaves, leaving outside the fortress a majority of desperately poor, oppressed and angry people (Gallopin et al., 1997).

In the **Great Transitions** scenario, global society, rather than descending into cruelty and chaos evolves to a higher stage. This idealised scenario implies radical structural change with respect to the historical trajectory, which could emerge, according to the GSG team, either through a

fundamental departure from the current path or as response in the wake of a destructive period of barbarisation. The range of possible Great Transitions scenarios is large, but two variants are analysed by the GSG in order to reflect at least part of this variation: Eco-communalism and a New Sustainability Paradigm.

Eco-communalism portrays a world of semi-isolated and self-reliant communities, made sustainable by high equity, low economic growth and low population. This world could emerge either from a New Sustainability Paradigm world if a strong consensus were to arise for localism, diversity and autonomy, or as a recovery from a world of Breakdown. In the latter case, from a situation of reduced population and a rupture of modern institutions, a network of societies guided by a "small is beautiful" philosophy and cured from the excesses of aggressiveness of the earlier Barbaric stage, such a society could emerge.

A **New Sustainability Paradigm** world, on the other hand, could emerge from the pull of other, already existing trends, in particular;

- from the strengthening of new social actors such as intergovernmental global organisations, transnational corporations, and non-governmental organisations; and
- from the appearance of new values that might anticipate strong cultural and behavioural changes in the general public (Gallopin et al., 1997).

The path to this new world could emerge from the backdrop of deepening environmental and social tensions, and develop as follows. Growing inequality, difficulties in managing migratory flows, and the resentment that comes with these tensions, fuel concern by governments, businesses and the general public about threats of social unrest and conflict. The conviction grows that over-reliance on profit as an engine for growth has been environmentally and socially expensive, and that better governance of all these phenomena is needed. Environmental problems become graver and a scientific consensus emerges that large-scale shifts in planetary climate and ecosystems are indeed possible and even very likely, reinforcing concerns about sudden catastrophic developments. Disenchantment with consumerist lifestyles becomes increasingly diffused prompting, in increasing numbers of people, a new quest for meaning in life, and fostering values of collective identity and global harmony. The circulation and diffusion of these ideas, especially among the young, is facilitated by the expansion of communications networks, by global meetings, by the coalescence of international political movements. The

tensions between these movements and the forces of conventional development start to mount. Some transnational corporations accept the challenge of a new eco-efficient business ethic, others resist change, but under popular pressure organised locally, nationally and globally, governments and corporations begin negotiations around a New Planetary Deal. Agreements are reached on international mechanisms for the redistribution of wealth, on population control policies and on environmental targets (Gallopin et al., 1997).

This change in values leads to a new metropolitan vision, inspiring the redesign of urban neighbourhoods around a more compact and integrated settlement model; the need for mobility and car use is reduced, communities become more integrated and secure; "tele-work" becomes more common; decentralized renewable energy systems increasingly meet the needs of these communities; production patterns become more self reliant and local environment is protected. At the international level, technology transfer and joint sustainable development initiatives lead to a new era of co-operation between rich and poor regions: the latter start adapting new technologies to their specific needs and soon innovation starts also flowing from poor to rich areas. In production, non-market constraints defined by social, cultural and environmental goals dictate new rules for efficiency of production and allocation. The time horizon for economic decisions is lengthened to decades, more in line with ecological processes. New technologies for sustainability develop (Gallopin et al., 1997).

A variety of policy mechanisms are put in place to achieve programs of sustainability; the public is kept informed about the effectiveness of these policies through publication of a variety of performance indicators. Governance takes more decentralized forms and mechanisms are established for decision making from local to global scales thus leaving communities with considerable leverage for controlling socio-economic and environmental policy decisions. Local communities have to meet environmental standards for GHG emissions and water use. Population growth slows and stabilizes at a relatively low level. Poverty is eliminated and GHG emissions are sharply reduced as lifestyles become much less energy intensive, and renewable energy systems and efficiency become the norm. Sustainable agricultural practices are universally adopted. Conflicts are resolved by negotiation. Economic development continues indefinitely, driven mostly by non-material production: services, culture, arts, sports and research (Gallopin et al., 1997).

World Business Council for Sustainable Development

The first scenario, aptly named **FROG (First Raise Our Growth)** describes a world where economic growth is the main concern, while sustainable development is considered important but not pressing (WBCSD, 1997). This is the dominant perspective in the developed and developing world alike. As a result GNP grows quickly around the world, but this leads to trade tensions and widespread environmental problems. Then nations start turning inward and the world economy goes into deep recession.

The scenario develops as follows (WBCSD, 1999). At first, Asian and Latin American markets expand rapidly, attracting foreign investment and technology transfers. This increases the competitiveness of many of these countries, which are then able to mount a commercial threat to firms of developed countries. The latter respond an increasing trade barrier, which provokes countervailing measures from the former. Rapid globalisation and liberalization of markets in the early years, together with fast urbanisation processes lead to serious inequity and in turn to social unrest. Furthermore, although in a number of developed and developing countries the state of the environment improves due to improved technology and to income effects leading to complacency, in other areas the environment deteriorates sharply. By the 2020s rising barriers to trade have slowed world growth significantly and with it the speed of technological innovation. Rivalry prevails in international relationships, preventing the possibility of co-operation to any significant degree to address environmental problems. As a result both the human and ecological environment deteriorate to the point of threatening their survival.

This scenario has clear implications for energy, technology and the environment. Coal and other fossil fuels dominate the picture, electricity is produced in large generating plants and transported long distances, since users in wealthy countries want them kept far away. The emphasis is on cheap technologies with investments based on short payback periods; hence nuclear and renewable energy are basically out of the picture, or confined to small niche markets due to their inability to compete on a price basis. As a result CO_2 emissions increase rapidly (WBCSD, 1999).

In this scenario, the first decade of the 21^{st} century starts with the collapse of the environmental movement after years of unfulfilled prophecies of environmental disaster, although concern for local environmental conditions, especially among the middle and upper classes in developed and developing world remains high. The idea of environmental limits to

economic development is lost and enforcement of the Kyoto Agreement with its confusing details is allowed to slip into oblivion.

Countries are concerned about securing energy supplies necessary to fuel growth. Increasingly, they turn to coal, which is cheap and abundant worldwide and manifests lower geopolitical risk. Environmental legislation requiring desulphurisation equipment or mining safety and land reclamation is increasingly superseded. China, concerned about possible threats to natural gas pipelines that would have to cross politically unstable areas, decides against their construction and instead increases consumption of abundant domestic coal. The fact that its use does not require expensive or new infrastructure and that technology is readily available and well tested is perfectly consistent with short-term business decisions.

Coal becomes an important energy source even in transport: burned in distant power plants (often located beyond national borders) and transformed into electricity it powers electric or hybrid cars that limit local pollution. Pollution from power generation is thus directly exported to poorer countries just as was pollution from manufacturing at the end of the 20th century. The use of cars grows in developed and developing countries alike; development of major transport infrastructure is unable to keep pace and congestion problems intensify as a result. With people spending more and more time stuck in the traffic, a market for cars equipped with entertainment and business devices develops. Long-distance transmission and energy conversion technologies, as well as battery technologies and mobile generation sources develop in this scenario, often as backup energy supplies in situations of disruptions (WBCSD, 1999).

Fossil fuels use in general remains high and oil product taxes are progressively eased. Middle Eastern oil producing countries also do well but are unable to control the market because of doubts in the reliability and security of their oil supply. Nuclear power continues its slow decline especially in some OECD countries due to its costs. There the difficulty of maintaining basic technology capabilities makes replacing existing capacity more difficult. In developing countries not endowed with significant coal resources, however, nuclear remains an interesting option backed by governments and the Japanese nuclear system industry is able to secure some of those export markets. Renewables (PV, wind, wave, and so on) as well as energy conservation technologies, due to their higher initial costs are unable to penetrate the market. Large hydro-projects in

developing countries cannot find the necessary funding due to the high-risk, low-trust financial environment and poor international co-operation.

With the creation of trade blocks, commercial exchanges and economic growth implode; technological change slows down everywhere, partly as a result of risk aversion in ageing populations. Social unrest develops within nations due to increasing income inequality and conflicts, fuelled by various kinds of fundamentalism, explode internationally. Only a few islands of safety survive in a sea of disorder, behind closed and protected walls: some city states, or wealthy communities, powered by clean photovoltaics, wind resources or hydrogen when the electricity supplies from distant coal facilities fail.

The **GEOpolity scenario** moves from the awareness of a looming environmental and social crisis particularly widespread in the first two decades of the 21st century, which leads to the creation of new global institutions to protect the environment and to preserve society.

In this scenario the prevailing "economic myth" is increasingly viewed as dangerously narrow, in the face of increasing signs of environmental stress and loss of cultural identity that results in social unrest (WBCSD, 1997). Traditional government institutions have lost credibility as problem solvers and multinational corporations are unwilling or unable to address global problems due to their focus on narrow self-interest, pushing citizens to search for new institutional frameworks.

The scenario starts at the beginning of the 21st century with a series of eco-shocks (floods, extraordinary weather events leading to crop destruction and even famine in various parts of the world), which drive home the idea that global environment is seriously at risk and that something must be done. As a result of this major shift in public mood a new authority is created out of the World Trade Organization and staffed by experts who had previously been involved in the enforcement of the Kyoto Agreement or by other technocratic elites from national bureaucracies (WBCSD, 1999).

The new supranational authority is named GEOpolity from "Global Ecosystem Organization" and immediately takes action to address the environmental threats at hand. First and foremost it puts in place rules and measures to reduce CO_2 emissions: tax increases on coal and oil, cut-backs in subsidies for high-carbon fossil fuels, support for nuclear energy, natural gas and renewables, stricter rules for authorising infrastructure with a high impact on the environment, and so on. Taxes and regulations are seen as

the quickest approach to shift the world's fuel mix and are preferred over more indirect measures.

These measures produce some immediate successes and are particularly accepted in countries with a tradition of authoritarian leadership or "dirigisme". Funding is granted to desirable projects that provide relatively large-scale solutions (hydropower, reforestation, wind farms, long-distance gas transport infrastructure, nuclear power stations). Research is promoted in some key areas (biotechnologies for new fuels production, improved battery storage, fuel cells, carbon sequestration and wherever ready results were achievable). Other renewables such as solar PV or wave power, that still lag on the learning curve or which do not provide large-scale solutions, and open-ended research receive much less support. Middle Eastern oil producing countries suffer from the high oil taxation levels, while North African gas exporting countries fare better (WBCSD, 1999).

The new concept of environmental and social responsibility is at first widely accepted even by businesses, in the name of a stable regulatory framework. Soon they start to actively collaborate in meeting some of the most ambitious infrastructure construction or retrofitting projects for power plants promoted by the GEOpolity technocrats, in an attempt to appease and influence them. Gradually GEOpolity becomes a self-referential bureaucracy cut-off from the consequences of its actions and by the early 2020s the failures of its dirigiste approach become evident. As a result of being locked in to mediocre technology or ill-chosen resources, cost effective reduction of other environmental gases is overlooked and in the end CO_2 emissions decline too slowly to attain a safe level within the planned horizon.

GEOpolity responds to public criticism by hardening its command and control measures, but a diminished sense of urgency and a fatigued civic sense provoke widespread rebellion against its authority. At the end of a couple of years of internal struggles which threaten to destroy entirely this form of oversight and ecological management, GEOpolity is recreated on the basis of different objectives: influencing consumer behaviour and reducing waste.

Ways to take advantage of low-cost, energy-efficient solutions are devised that make use of innovative financing schemes and decentralised market mechanisms such as tradable permits, price rebates for energy savings, set-aside programs, reforestation incentives, and so on. Popular support for increasing energy efficiency is mobilised by better-designed communications campaigns stressing personal participation in the effort

to respond to environmental problems. As a result very large CO_2 emission reductions are achieved. However many of the indirect methods used to encourage these reductions of CO_2 emissions manifest problems and weaknesses; furthermore, energy-saving measures can only take the world so far, after which creation of new forms of clean energy becomes necessary, and they start slowly becoming available.

These developments, coupled with the change in lifestyles, increased education levels and the social improvements that in turn bring slower population growth, begin to outline a pattern of sustainable growth, albeit one that is slow, pre-planned and with many choices guided by the government (WBCSD, 1999).

The **Jazz scenario,** like the music style it recalls, is characterised by the coexistence of diverse players joining in ad-hoc alliances to produce a desirable outcome: in this specific instance to solve social and environmental problems (WBCSD, 1997). It describes a world of social and technological innovations and experimentation, with a very dynamic global market, a wide circulation of information and a high degree of transparency. A deregulated world in which citizens do not necessarily turn to central governments for the solution of their problems, where governments have a minimal caretaker role; and in which the economy progressively advances along the road of dematerialization.

In this new business environment, the energy industry undergoes rapid transformation into a service industry characterised by entry of newcomers, from diverse market segments, who come attracted by the prospect of economic gains. Retail store chains, household appliance producers and the like, start diversifying their product range to cover customised energy service bundles, or equipment for small scale decentralized power generation, bringing direct competition to established energy utilities and forcing down energy prices. Some energy companies, especially those enjoying large liquidity margins, are able to enter the lucrative market of building renovation for improved performance; others are able to acquire a captive market by offering deals on homes as long as heating and cooling systems remain based on the energy product they sell (electricity, or gas) for a sufficiently long period. Energy Service or Energy Saving Companies scan the world in search for self-funding projects and attractive profit margins: old coal fired plants are converted into highly efficient ones, ageing nuclear plants are being revived through innovative financial deals, housing stock is retrofitted with insulation. Lucrative markets open up in computerised

monitoring systems for reducing downtime in power plants or controlling transmission losses (WBCSD, 1999).

As deregulation continues and energy subsidies are progressively eliminated, energy companies via their subsidiaries enter the market for energy systems manufacturing, especially in areas that still offer interesting margins for technological improvement, as in the case of renewables. Advances in biotechnologies are exploited by multinational corporations to genetically engineer bacteria or algae that transform biomass into oil.

Small power plants become important because they are easier to fund and provide a good way to stay close to the market: a useful feature in a service-centred world. Sales of small gas turbines boom, as do all modular systems as part of a general trend towards decentralised energy sources. Fuel cells and their residential applications for small-scale power generation fit perfectly this trend, in which old style utilities survive merely as a backup for the remaining power disruption risk (WBCSD, 1999).

This radical shift in industrial paradigm does not take place without casualties: businesses that cannot adjust and ride or anticipate the new trend do not survive. Competition is ferocious and often carried out without formal restraint, and those left out develop feelings of resentment. The focus on profits sacrifices other resources such as people and the environment. By the early 2020s a crisis develops and a citizens' movement calling for the "greening" of the economy sweeps the globe, using the Internet and other fast communications networks. One initial result is the creation, of a unitary tax on all activities and transactions that have an environmental impact (WBCSD, 1999).

However, as authority in a Jazz world is too dispersed and governments cannot manage the transition to a more sustainable path, the solution must develop through a voluntary "greening" of the main business actors and through the stipulation of Consortium Agreements that set out guidelines on how firms must act on environmental and other sustainability issues. As the Agreements do not constitute legal obligations, verification of their implementation is left to the joint action of consumer watchdogs, networks of concerned citizens, and insurance firms, who could refuse insurance coverage to firms found not in compliance with most respected environmental Agreements. This monitoring system, largely based on the transparency of the market and on free circulation of information on the environmental performance of individual business, leads to the creation of protocols, or Trust Validation

Systems. These constitute informal trust authorities, neither business nor governmental nor judicial, which publicise track records of partners and the criteria used, and the success of which is measured by consumers' respect and size of membership (WBCSD, 1999).

Within this framework, the new business forms continue their earlier growth, becoming the accepted way of functioning. Most specialise in the provision of energy or transport services (e.g. business trips) rather than goods (cars, for instance), and clients are happy to be relieved of the "do-it-yourself" complications. Technology and open trade make small regions economically viable, and these gradually start separating from larger nations without recourse to conflicts such as civil wars.

However, these trends do show their downside: short-term focus in research and development, difficulties in planning ahead and in funding large infrastructure projects; spot markets in energy commodities making planning of future prices impossible; weak traditional governments giving the impression that everybody is left to his own devices and that nobody is in control, and although the new business style is locally clean, that nobody is really looking out for global environmental effects. It is a slightly unsettling world of thousands of opportunities and open-end solutions (WBCSD, 1999).

Intergovernmental Panel on Climate Change Scenarios

The **A1 storyline** and scenario family describes a world characterised by very rapid economic growth, a population trend that peaks around 2050 to decline afterwards, and swift introduction of new and more efficient technologies (IPCC, 2000). Other relevant characteristics are a continuation of globalisation trends, and increasing convergence of development among world regions, leading to greater interregional equity in income distribution. The three technology variants of this storyline concern, as mentioned, alternative directions in energy-technology developments. The first (A1FI) is characterised by emphasis on fossil fuel technologies, leading to worsened environmental conditions especially with respect to GHG emissions and climate change risk. The second (A1T) is characterised by development of non-fossil fuel technologies leading to a marked improvement of environmental conditions and a mitigation of climate change. The third is characterised by a fuel/technology mix that is more balanced across the fossil/non-fossil spectrum, due to uniform improvement rates across technologies, resulting in a moderate improvement of environmental conditions.

The **A2 storyline** and scenario family describes a world characterised by self-reliance, slower economic growth than in other scenarios, preservation of local identities and values, continuously increasing global population and therefore much less rapid growth of per-capita income (IPCC, 2000). With a slowdown of globalisation processes and a lower degree of markets openness, economic development is primarily oriented to regional markets, differences in income distribution across regions increase, while technological change is slower and more fragmented. As a result environmental conditions deteriorate globally and even more dramatically in some local cases.

The **B1 storyline** describes a world characterised by a population trend very similar to the one in the A1 scenario, a fairly sustained growth of the world economy, which is increasingly globalised but driven by the service and information sectors (IPCC-WGIII, 2000). Consequently important reductions in materials intensity are achieved and clean and resource efficient technologies are progressively introduced. The increase in world GNP coupled with a slowdown and reduction of global population allows for increased per-capita income and an improvement and convergence in inter-regional equity. The emphasis on global solutions to economic, social and environmental sustainability coupled with favourable technological developments result in dramatic improvement of environmental conditions even in the absence of specific climate policies and initiatives.

The **B2 storyline** outlines a future world that emphasises local solutions to economic, social and environmental sustainability. Population increases continuously, although at a slower rate than in the A2 scenario; economic growth is slower than in other scenarios, and technological change less rapid, both as a result in part of lower degree of market openness (IPCC-WGIII, 2000). The concerns for environmental protection and social equity that inspire the values in this society are addressed more at the local and regional level, through changes in individuals' behaviour more than through improvement of technologies.

Millennium Project

Cybertopia is a scenario of open trade and continuing globalisation, low government involvement, intensely developed communications and high security. The explosive growth of the Internet accelerates globalisation in all forms. Cyberspace is the medium of human activity: the majority of human waking hours are spent in cyberspace, either for work, play, leisure or education. The impressive growth in international activity is translated

in increased support for and responsibilities of such organisations as the UN, the WTO, IMF and others that provide global standards and co-operation for international business. Individuals set their own values and use global networks to support them. Democracy flourishes. International partnerships are formed to manage global education, tele-medicine, environmental monitoring (in co-ordination with UNEP). Developing countries make remarkable progress via tele-education, tele-medicine, and tele-business partnerships. Technology spreads globally, promoting leap-frogging in developing countries. As a result, life expectancy in Africa rises, increasing population levels despite falling birth rates. The gap between developed and developing countries narrows. Population growth slows down globally, following improved literacy, empowerment of women, lower infant mortality, and better family planning. Unfortunately, unemployment is still a problem in poor countries and many people are left out of the knowledge economy. In China and India service activities represent over 50% of GDP, diminishing the need for external capital to finance growth. Cyberspace lowers energy demand in various ways: through an increase in energy efficiency (virtual experience substitutes for travel, teleconferencing is more common), through better monitoring of inefficient industries, and through a push for renewable energy resources to substitute for fossil fuels. As a result energy demand doubles in 45 years instead of the 30 years previously estimated. Environmental monitoring is facilitated; economists can use databases to establish systems of taxation and credits based on the use of the "commons". However the environment and biodiversity still hung in the balance (ACUNU, 1998).

The Rich Get Richer is a world of open trade, low government involvement, intense communications and low security. In the first part of the period considered, income inequality grows between rich and poor countries and between rich and poor individuals in the same country; after 2025 however, conditions improve even in poor countries. The rich get richer and the poor get poorer. This evolution is not uniform across countries: among the poor ones, those with stronger institutional capacity can initiate reforms, invest in human capital and fight corruption and fare better. Relatively high population growth compounds the poverty problems. Rich countries experience a period of rapid growth, as advancements in science and technology lead to improvements in productivity in nearly al sectors of the economy. The forces of globalisation work to their benefit, offering cheap labour to businesses that invest in poor countries. International cartels control most of the planet's natural resources. Governments do not perform well and in some countries even abdicate their responsibilities in

such sectors as public health and education; corruption abounds. Then wars break out, especially among developing countries; uprisings explode, triggered by tensions associated to migrations, water shortages and environmental deterioration; meanwhile, rich countries keep prospering. The turnaround is caused by the recognition by multinational corporations that growth can continue only if markets develop, which requires the development of markets in poor areas of the world, and the increasing of the purchasing power of their populations. As a result corporations mobilise resources to encourage the real development of poor countries, through investments in education, micro-credit, environmental remediation programs, and through higher wages. By 2025 comes also the realisation that global warming is already a fact, hence corporations see clear business opportunities in investing in alternative energy systems, although developing countries continue to rely on cheaper fossil fuels. By 2030 vigorous action to reduce the rate of GHG emissions has begun, technologies to improve energy efficiency in transport and other sectors are rapidly introduced, while new generation nuclear power and hydrogen-fuelled systems are being developed. So, by 2050 living conditions have improved for the general population, and although poverty remains, vigorous capitalism and global trade have fulfilled many of their promises (ACUNU, 1998).

A Passive Mean World. This is a world of isolation and barriers to trade, stagnant communications but high government involvement and high security. Lack of jobs is the main problem, as the rate of population growth has outpaced the rate of job creation nearly everywhere. Where countries are able to trade within a major trading block things are not too bad, but in areas such as Africa labour surplus is a serious problem. Unemployment and underemployment produce pressures on economic systems and foster political unrest. The unsatisfactory economic situation pushes environmental concerns backstage. Developed countries' economies slow down due to trade limitations while productivity gains translate into fewer jobs. Technology development decelerates too, while ageing populations increase the burden of social security spending on public budgets. Living standards rise slowly in most places and even drop in others. The movement towards democracy stagnates. By 2025 things begin to unravel. The downsizing of expectations leads to vast discontent, and huge distrust of governments. Large companies restructure continuously but many are unable to keep abreast of this fiercely competitive economy. Small companies survive better and individuals are forced to high mobility to follow jobs. Then trade wars erupt between the blocs and protectionism is rampant, taking all possible forms: from aggressive protection of

intellectual property to restrictive immigration policies. Multilateral free trade agreements come under intense pressure and trade diminishes. The US and the European Community close their markets to newly industrialised countries and jobs continue to disappear. It is a tough world even for rich countries. Only China and India keep developing at a sustained pace, although unevenly. Elsewhere in developing countries peace and security is rare, while tensions, demagoguery and nationalism are increasing, military forces are building up and international institutions lose power. The UN survives through a series of reorganisations, but is weakened and lacks leadership. Soon regional conflicts start to develop and the UN cannot cope. Crime and terrorism grow and the only goods that seem to circulate freely are weapons (both conventional and unconventional). In this environment people start turning for help towards faith, religion, community, and begin retreating more and more into closed communities (ACUNU, 1998).

Trading Places. This is a world of open trade, low government involvement, intense communications but low security. The booming economies of East and Southeast Asia (and to a lesser extent Latin America take advantage of this favourable trade environment and China's GDP keeps growing at double-digit rates throughout the first part of the new century, to stabilise at lower rates later. Improved economic development, increased literacy, and empowerment of women brought increased life expectancy almost everywhere, with only Africa lagging behind. Meanwhile the US and Western Europe experience sluggish growth and heavy social burdens due to ageing populations. Privatisation and deregulation offer only partial relief to strained government budgets; unemployment is low but underemployment is high. For most people life is hard, compared to the past but still bearable. Conflicts inevitably emerge between social and economic aims while the environment is a low priority. The international monetary system survives but falls into disarray as the dollar becomes less stable. In contrast the WTO thrives in its role of regulating and keeping open the flows of international trade. Relocation of industrial plants to the rapidly developing markets of East and Southeast Asia and to Latin America creates a drain of productive resources in the US and Western Europe. The latter's leadership in non-manufacturing industry (IT, health care, pharmaceuticals) remains but in many other sectors is gradually eroded: Asia's economic and political power is increasing, as is its research and development capacity. By 2025 China is the dominant regional military power. The environment suffers: fresh water is in short supply in many regions and atmospheric CO_2 increases by 50%. Energy demand

doubles by 2050. By the turn of the first half of the 21st century the Western economies manage to rebound, but they have lost their political, military and economic clout. In brief, the emerging countries have emerged (ACUNU, 1998).

Country Scenarios

Canada: Energy Technology Futures

Life Goes on is a world of slow innovation, closed markets and grey (rather than green) environmental etiquette. A world in which developing countries fail to participate in the FCCC efforts and discussions on environmental issues disappear from the international scene. Economic growth is slow (about 2% per year). Developed and developing countries alike return to protectionist policies and this restraining of markets fosters slow technological innovation. Developing countries focus on increasing domestic standards of living. Environmentally, it is a world that builds on existing technologies and offers few chances of becoming "greener".

Grasping at straws is a scenario of green environmental etiquette, reasonable economic growth (about 2% per year yet falling over time) and wide-open global markets but a slow pace of innovation. Governments of developed countries try a hasty response to the climate change issue by rapidly deploying off-the-shelf technologies, hoping that this provides a quick solution. Some near-term results and both economic and political advantages are achieved. But the focus on deployment and near-term activities produces little investment along the early stages of the innovation chain: the lack of commitment on long-term R&D leaves countries with a limited pool of technologies from which to draw. By 2030 very few innovative technologies are available to address the climate change issue. It is a light-green world in the near term that turns grey at a later stage.

Taking care of business is a world of rapid innovation, open markets and grey environmental etiquette: a world driven by economics and profit and dominated by interconnected transnational companies. Capital stock turnover is fast and economies are strongly independent. Expanded economic growth (about 4% per year) leads to the overlooking of increasing inequity between developed and developing countries and

environmental issues. In developing countries rapid population growth and increasing poverty and environmental pressure lead to social conflict. However, the issue in international discussion is wealth distribution rather than the environment: despite lack of attention for the environment, technological advances do to some degree reduce GHG emissions.

Come together is a world of open markets, rapid innovation and high levels of environmental etiquette. Consensus prevails among industry, government and the public on environmental matters and similar views are shared internationally. Multinational companies exert political as well as economic power and influence government on environmental, trade and monetary issues. The world is highly interconnected and new technologies are openly developed, traded and applied in innovative ways across all sectors. Canada is well placed in this global market and its industries are able to innovate both products and processes. This world is mid-green in colour: reduced GHG emissions realised through technology improvements are partly offset by expanded industrial activity through continuing worldwide economic growth (Cliffe, 1999).

The Netherlands: Long-term Outlook for Energy Supply

Free Trade is a world with a thriving economy, competitive markets, close economic co-operation but no willingness to resolve jointly the drawbacks of economic growth. Fuels like uranium, coal, gas, biomass and heavy oil are cheap, and low energy prices make conservation uninteresting and render non-competitive the more expensive renewables. Technology is aimed at increasing productivity rather than improving the environment. CO_2 concentrations are high but not seen as a priority concern. The Netherlands in this world specialises in trade and services, while manufacturing has relocated elsewhere largely as a consequence of the strong pro-environment positions taken earlier by the Dutch government. Mobility of people and goods is high and transport infrastructure is developed along spatial corridors. Environmental quality is poor and quality of life mediocre for Dutch citizens, but this is considered a price to pay for prosperity. In the energy domain, primary demand has declined due to the shrinking of the industry and its replacement by service activities, and electricity (mostly imported) accounts for almost 50% of final energy demand. Dutch gas reserves are exhausted. Energy supply in the world market is abundant and prices of energy carriers are nearly equal: price differentials are due to different infrastructure and equipment needs. For reasons of competitiveness plant- scale economies are exploited

to the maximum and countries have by now specialised in different energy products: electricity production is a European affair. The use of coal is unhampered by environmental concerns and inefficient power plants are exploited to the end of their physical life. In view of the already existing gas-distribution infrastructure, coal gasification is an option for the Netherlands. Other natural gas is imported and used in combined heat and power generation. Furthermore, the depleted gas deposits are converted to become Europe's gas storage facilities. Nuclear energy and solar PV are not sufficiently competitive while biomass is cheap and abundant and wind power from offshore parks has become an export product. Transport is still dominated by (improved) combustion engines and large private cars since oil products are still relatively cheap. In residential spaces cheap electricity favours the use of heat pumps but gas heating is also used.

Ecology on a small scale is a world where non-material values and the environment are appreciated. Economic growth has slowed and with it environmental deterioration. IT reduces the need for physical mobility. Although there is awareness of global problems, solutions are sought locally. International organizations like the UN and WTO or the European institutions are mistrusted. Technology development reflects dominant values of high quality and small scale. Clean technology and autonomous energy systems are popular. In the Netherlands, government is decentralised, production is on a small scale, people live in small communities and have little need for mobility. Concern about social issues is felt as a strong personal commitment. Environmental quality is highly valued and in the energy domain leads to small autonomous systems, mostly based on renewables. Recycling is profitable. Due to the attention put on efficiency, energy demand is only slightly higher than in 2000, at 2000 Pj; slightly less than half of final demand is for electricity. There is no public support for large-scale infrastructure and indigenous gas is mostly used domestically or serves as emergency stock. Gas flows other than biogas are decarbonised as much as possible and delivered to small-scale installations (fuel cells, small CHP). Biomass is processed locally or regionally, mostly in rural areas. Renewable energy (solar PV, wind) is valued also in the perspective of self-sufficiency. Nuclear plants have been closed and there is little interest for clean coal. Storage of energy is handled locally and for mobility, besides the bicycle, preference goes to hybrid cars or public transport.

Isolation is a world directed by short-term monetary gain, with little or no international co-operation and restricted trade, which takes place mostly

within blocks. Like other trading blocks Europe pursues self-sufficiency in food, raw materials and energy. China and the US pursue isolationist courses. This leads to overall slower growth and limited technological improvement. In the Netherlands the central government remains strong but is weak with respect to the business sector and does not impose restrictions upon it. Nationalism, family and self-interest are dominant values. The environment is not important while health is. The main ports lose importance due to restricted trade. Energy self-sufficiency is important everywhere. Energy demand in the Netherlands is around 3000 Pj; one third of final demand is for electricity. The country relies on its own gas; oil is relatively expensive due to cartel power but its consumption is restricted as much as possible. Nuclear and renewables are attractive options but while wind and solar are frequently used, the Netherlands does not venture into building its own nuclear plants, preferring to buy power. Clean coal technologies are used as a compromise between environmental and self-reliance concerns. Biomass (mainly agricultural wastes) is used locally and biomass for energy production competes for land with food production. Large- and small-scale CHP is diffused. Mobility has declined, as has tourism. Cars are smaller and fuel-efficient, and gas-powered fuel cells have taken off. Railroads and inland waterways account for a substantial share of goods transport.

Great solidarity is a world where the solution to global problems (like hunger, poverty, resource scarcity and climate) is handed over to powerful global institutions like the UN, or the WTO. Co-operation fosters economic growth, environmental awareness and optimism about progress leading to rapid technological development. Large multinational corporations co-operate with supranational institutions for the improvement of the environment and of working conditions. European co-operation is broadened and deepened and some countries including the Netherlands start forming federations. The Netherlands is very prosperous and able to exert leadership in Europe on clean technologies and development aid: its industries specialise in eco- and energy-efficiency, and the chemical industry is strong. Citizens are wealthy, mobile and used to luxury and comfort but display eco-awareness in their lifestyles. Energy demand, despite efficiency, life cycle management and recycling, is enormous at 4500 Pj, but owing to a flourishing trade in emission rights the country can afford this energy intensity. International agreements allow the optimisation of energy production, transport and use and the Netherlands profits from its placement in the international grids. The country's gas reserves are long gone but the distribution infrastructure continues to be

used for other gaseous fuels while depleted gas fields are used for CO_2 storage. Energy supply is both centralised and decentralised and new energy technologies thrive. In particular renewables are used wherever possible and renewable sources imported where convenient. Biomass is used both for energy and as feedstock in the chemical industry. Nuclear energy is available and safe. Mobility is high, and to reduce CO_2 emissions is often on electrically powered large-scale public systems for transport between large European agglomerations (TGV, Magnetic Levitation trains) or on highly sophisticated urban systems. Fuel-cell cars powered with hydrogen stored in nanotubes are standard. About one half of the transport of goods takes place by rail or on inland waterways. Each of these scenarios, as we have seen, has different implications for the Netherlands in terms of energy demand, structure of the energy system, and technologies. When exploring different scenarios, common elements are the ones to which attention should be paid because robust strategies can be built on them. Common elements in the above scenarios point to a few reasonable certainties. These include: the increasing importance of electricity consumption in all scenarios; the continued importance of the existing gas infrastructure; the robustness of the wind power option and to a large extent of biomass options; the relevance in most scenarios of the Netherlands as an energy distribution centre; the critical importance in all cases of energy storage technologies. A rather uncertain element, on the other hand, is the fuel choice for traffic growth.

The United Kingdom Foresight Program – Energy Futures

World Markets is a scenario characterised by emphasis on private consumption and highly developed and integrated world trading systems. Consumption levels and mobility are high while sustainable development goals are marginalized, being regarded as international political concerns. Similarly concern for inequality and social exclusion is weak, while social tensions are on the rise. The role of governments in economic management, regulation of utilities and energy markets is kept to a minimum and provision of public service is reduced in order to keep taxes low. Large firms dominate global markets. The economic structure moves towards the service industry, while traditional manufacturing migrates towards the developing world. Global standards and best practices for technologies emerge and are quickly adopted in many sectors. Fossil fuels, particularly natural gas dominate the energy markets and, due to the decline of traditional oil production, by 2020 exploitation of non-conventional oil and tar sands begins. Fuel demand for transport keeps

increasing. Electric power demand grows, and new investments are generally in modular distributed power systems. Low energy prices discourage conservation and energy efficiency except on an economic efficiency basis. Renewable energy sources do not take off and the revival of nuclear power does not materialise due to their costs. Households get smaller but dwellings get larger and equipped with more appliances as incomes grow. Mobility of the workforce increases. Gated communities develop to insulate the wealthy from the disadvantaged (UKDTI, 2000).

Provincial Enterprise is a world of consumerist values emphasising the short term, coupled with policymaking systems that assert national and regional concerns and priorities. Market values remain dominant but markets are mostly national or regional due to protectionism. Sustainability as a political objective nearly disappears. Growth is sluggish in the UK (1.5% per year) but stronger globally (4% per year). Constraints to growth include capital and resource shortages. Fossil fuel supply is plentiful and there is a tendency to preserve or protect national fuel resources. Energy prices are for this reason higher than in the previous scenario. However energy efficiency is limited, due to lack of capital and low environmental priorities. Renewables do not develop. The high cost of housing counters the trend towards smaller households; and lower incomes discourage ownership and excessive use of appliances (UKDTI, 2000).

Global Sustainability is a world in which social and environmental values are taken into account in economic decisions, and in which environmental problems are dealt with through strong collective action and global institutions. There is greater co-operation between national and international levels of governance; global economic, social and environmental agreements are negotiated providing a framework for global trade consistent with international equity and sustainable development goals. Access to education is widespread. Working hours decline and the labour force is highly mobile. Global markets for training, education and tourism decrease cultural distances. The greening of business is pervasive with adoption of best available technologies. Some developing countries experience high growth rates, helped by high investment levels and low interest rates worldwide. Household formation is reduced due to more collectivist values and controls on new housing development. Dwelling size grows less than could be expected and construction codes stress high efficiency and environmental performance. Similarly the number and range of appliances in homes grows but energy consumption is limited by high efficiency standards. Reductions in residential energy use are limited, despite the diffusion of green attitudes

among consumers. Natural gas is the dominant energy source until 2010, but afterwards renewables gain a large market share. Zero-emission fossil fuel options such as large-scale carbon sequestration begin to play a major role in the UK after 2010. Solar power takes up a large market share after 2020. Nuclear power sees a revival and hydrogen becomes a significant energy carrier by 2030, following construction of production, storage and distribution infrastructure. Gas micro-turbines and fuel cells for small domestic generation are popular and lead the way to later use of hydrogen. Diffusion of distributed generation fosters development of innovative technologies for the control, transmission and storage of power. Energy suppliers move towards the provision of integrated services, enhancing the uptake of energy-efficient measures. Energy prices to the final consumer, however, are high due to the large investment in expensive new technology (UKDTI, 2000).

Local Stewardship is a world where strong national and regional governance allows social and ecological values to play an important role in the development of markets and behaviour. Political systems are transparent, participatory and inclusive at a more local level, with extensive provision of public services such as health and education. Local cultural identities are revived as are family values. The flow of culture, people, capital and goods across economic and political boundaries however is constrained, and international economic and political institutions are mistrusted except for mediation between countries. Households get larger and life in small communities is preferred to life in large cities, but the need to preserve agricultural land leads to more compact urban development, with small houses. Consumers are oriented towards a green purchasing etiquette and utilities emphasise sustainability and service provision. Household consumption declines slightly and total domestic energy consumption falls by 1.5% per year. Concerning fuels the emphasis is on local energy sources, whether fossil or non-fossil. A wide range of renewable technologies is exploited but energy production is small scale. Combined heat and power production flourishes. Coal is used but under strict environmental controls. Small scale nuclear becomes acceptable on grounds of self-reliance. Green pricing is widely practised and favoured by consumers, while high-energy prices lead to large-scale adoption of efficiency measures. Overall energy demand falls and becomes less carbon intensive (UKDTI, 2000).

APPENDIX II: SCENARIO COMPARISONS

This Appendix discusses two scenarios within the IPCC A1 scenario family that provide particular relevance for framing our analysis: the A1T case, in which rapid technological change plays in favour of non-fossil fuel energy technologies, and at the A1B case, in which rapid technological change has a balanced impact on both fossil and non-fossil-fuel technologies. For comparative purposes the main characteristics of the six marker scenarios of IPCC are shown in Table A.II.1. Tables A.II.2 and A.II.3 provide at a glance some of the quantitative features of two specific A1B and A1T scenarios, quantified with IIASA's MESSAGE model, for the projection period 1990-2050[1].

Figures A.II.1 to A.II.6 provide a graphical representation of the main trends of these scenarios, and compare them with IEA's WEO-2002 reference scenario (which, however, only runs to 2030). The A1B and A1T scenario outlines provide an initial quantitative framework for population, income growth and energy demand projections, on which we impose our targets or norms to obtain the SD Vision scenario.

The characteristics of the SD Vision scenario are illustrated in tables A.II.8 to A.II.12.

1. The spreadsheets containing the summary results for these two scenarios have been obtained from the SRES/CIESIN website http://sres.ciesin.org/final_data.html. However additional details on the transport sector have been obtained directly from Keywan Riahi and Neibosa Nakicenovic at IIASA, to whom go our thanks.

Table A.II.1 IPCC/SRES Marker Scenarios 1990-2020

	1990						2050						2100					
	A1-B	A1-FI	A1-T	A2	B1	B2	A1-B	A1-FI	A1-T	A2	B1	B2	A1-B	A1-FI	A1-T	A2	B1	B2
Population, Million	5262	5293	5262	5282	5280	5262	8704	8703	8704	11296	8708	9367	7056	7137	7056	15068	7047	10414
GNP/GDP (mer) Trillion US$	20.9	20.7	20.9	20.1	21.0	20.9	181.3	164.0	187.1	81.6	135.6	109.5	528.5	525.0	550.0	242.8	328.4	234.9
GNP/GDP (ppp) Trillion (1990 prices)		na	26		3971	26		na	186		15569	114		na	535		46598	232
Primary Energy EJ																		
Coal	93	88	91	92	105	91	186	475	119	294	167	86	84	607	25	904	44	300
Oil	143	131	128	134	129	128	214	283	250	228	228	227	125	248	77	0	99	52
Gas	73	70	71	71	62	71	465	398	324	275	173	297	576	578	196	331	103	336
Nuclear	6	24	7	8	8	7	123	137	115	62	105	48	78	233	114	234	165	142
Biomass	50	0	46	0	3	46	193	52	183	71	95	105	376	123	370	162	67	315
Other Renewables	10	24	8	8	61	8	167	86	222	42	46	107	987	284	1239	86	36	212
Total	376	336	352	313	368	352	1347	1431	1213	971	813	869	2226	2073	2021	1717	514	1357
Primary Energy%																		
Coal	25	26	26	29	28	26	14	33	10	30	21	10	4	29	1	53	8	22
Oil	38	39	37	43	35	37	16	20	21	23	28	26	6	12	4	0	19	4
Gas	19	21	20	23	17	20	35	28	27	28	21	34	26	28	10	19	20	25
Nuclear	2	7	2	3	2	2	9	10	9	6	13	5	3	11	6	14	32	10
Biomass	13	0	13	0	1	13	14	4	15	7	12	12	17	6	18	9	13	23
Other Renewables	3	7	2	3	17	2	12	6	18	4	6	12	44	14	61	5	7	16
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Cumulative Resources Use, ZJ																		
Coal	0.1	0.1	0.0	0.0	0.0	0.0	9.1	14.6	8.1	9.5	8.5	5.7	15.9	37.9	11.7	46.8	13.2	12.6
Oil	0.1	0.1	0.0	0.0	0.0	0.0	12.7	10.4	11.3	13.9	11.6	12.0	20.8	29.6	20.8	17.2	19.6	19.5
Gas	0.1	0.1	0.0	0.0	0.0	0.0	13.9	12.7	9.7	8.7	7.5	8.6	42.2	40.9	25.0	24.6	14.7	26.9
Cumulative CO_2 Emissions GtC	0.0	0.0	0.0	0.0	0.0	0.0	730.6	820.9	623.1	728.6	599.0	554.5	1492.1	2182.3	1061.3	1855.3	975.9	1156.7

Source: http://sres.ciesin.org/final_data.html

Table A.II.2 Summary Results for the SRES MESSAGE A1B Scenario

MESSAGE A1B Scenario - World	1990	2000	2010	2020	2030	2040	2050
Population - Million	5262	6117	6888	7617	8182	8531	8704
GNP/GDP (mer) Trillion US$	20.9	26.7	37.9	56.5	89.1	135.2	181.3
GNP/GDP (ppp) Trillion (1990 prices)	26	33	47	67	97	139	181
Final Energy EJ							
Non-commercial	38	28	22	16	10	7	5
Solids	42	58	59	67	73	70	48
Liquids	111	125	160	204	254	303	357
Gas	41	48	67	85	104	135	164
Electricity	35	47	70	107	164	232	311
Others	8	10	20	38	58	84	122
Total	275	316	398	517	662	830	1005
Primary Energy - EJ							
Coal	91	105	120	157	194	227	210
Oil	128	155	172	198	225	250	281
Gas	71	85	128	178	250	320	378
Nuclear	7	9	12	19	34	55	84
Biomass	46	47	63	87	120	155	204
Other Renewables	8	13	29	52	78	134	240
Total	352	415	524	689	901	1141	1397
Cumulative Resources Use - ZJ							
Coal	0.0	0.9	2.0	3.2	4.8	6.7	9.0
Oil	0.0	1.4	3.0	4.7	6.7	8.9	11.4
Gas	0.0	0.7	1.6	2.9	4.7	7.1	10.3
Cumulative CO_2 Emissions - GtC	0.0	75.3	162.0	262.8	383.6	528.0	688.0
Carbon Sequestration - GtC							
Land Use – Million ha Total	12949	12949	12949	12949	12949	12949	12949
Anthropogenic Emissions (standardized)							
Fossil Fuel CO_2 - GtC	5.99	6.90	8.31	10.56	13.21	15.51	16.47
Other CO_2 - GtC	1.11	1.07	1.04	0.26	0.12	0.05	-0.02
TOTAL CO_2 - GTC	7.10	7.97	9.36	10.81	13.33	15.56	16.45

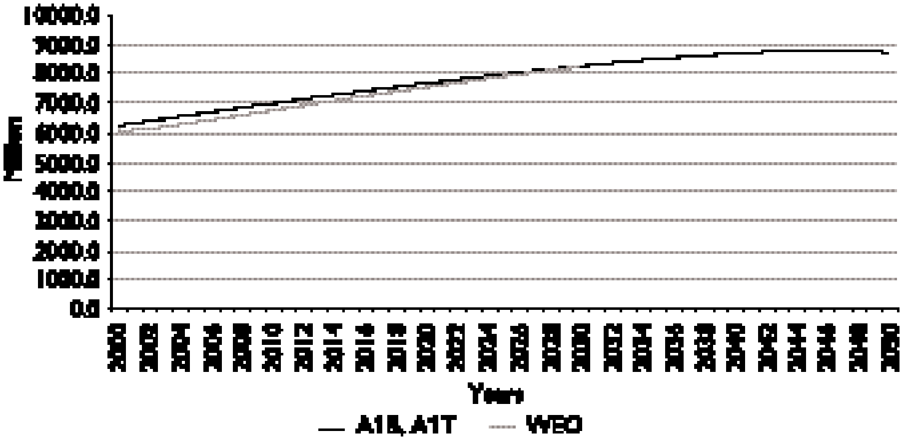
Source: http://sres.ciesin.org/final_data.html

Table A.II.3 Summary Results for the SRES MESSAGE A1T Scenario

MESSAGE- A1T Scenario - World	1990	2000	2010	2020	2030	2040	2050
Population - Million	5262	6117	6888	7617	8182	8531	8704
GNP/GDP (mer) Trillion US$	20.9	26.8	36.8	57.0	91.3	135.4	187.1
GNP/GDP (ppp) Trillion (1990 prices)	26	33	46	67	99	139	186
Final Energy - EJ							
Non-commercial	38	25	20	16	10	7	5
Solids	42	60	66	71	72	46	31
Liquids	111	125	157	193	246	300	344
Gas	41	48	66	83	107	135	155
Electricity	35	48	66	100	153	209	275
Others	8	12	18	33	48	61	83
Total	275	317	393	495	634	757	893
Primary Energy - EJ							
Coal	91	106	125	151	180	153	119
Oil	128	155	172	193	223	241	250
Gas	71	87	124	166	231	288	324
Nuclear	7	8	11	17	40	78	115
Biomass	46	46	55	75	104	137	183
Other Renewables	8	15	25	48	73	122	222
Total	352	416	513	649	850	1018	1213
Cumulative Resources Use - ZJ							
Coal	0.0	0.9	2.0	3.2	4.7	6.5	8.1
Oil	0.0	1.4	3.0	4.7	6.6	8.9	11.3
Gas	0.0	0.8	1.6	2.9	4.5	6.8	9.7
Cumulative CO_2 Emissions - GtC	0.0	75.3	162.1	260.3	373.4	498.6	623.1
Carbon Sequestration GtC							
Land Use – Million ha Total	12949	12949	12949	12949	12949	12949	12949
Anthropogenic Emissions (standardized)							
Fossil Fuel CO_2 - GtC	5.99	6.90	8.33	10.00	12.26	12.60	12.29
Other CO_2 - GtC	1.11	1.07	1.04	0.26	0.12	0.05	-0.02
Total CO_2 - GtC	7.10	7.97	9.38	10.26	12.38	12.65	12.26

Source: http://sres.ciesin.org/final_data.html

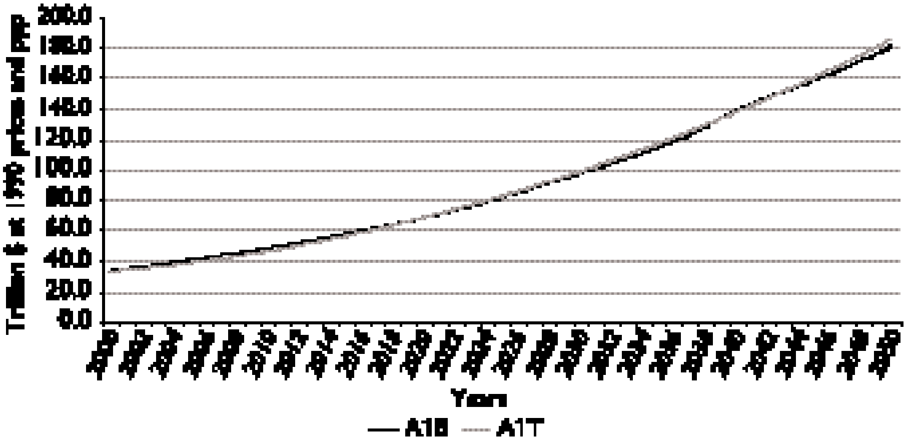
Figure A.II.1 Population Projections



Source: Elaboration on data from SRES and IEA's WEO - 2002.

Figure A.II.1 shows the population projections for scenarios A1B and A1T and those for the WEO till 2030. The WEO projections are very close to the A1 case, so as to make the two curves hard to distinguish (the two lines almost coincide).

Figure A.II.2 GDP Projections



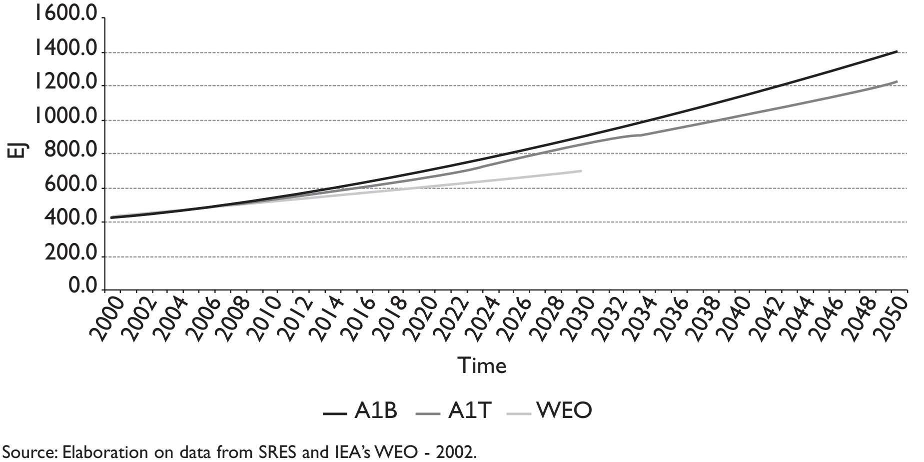
Source: Elaboration on data from SRES.

Figure A.II.2 shows the GDP projections for the A1B and A1T scenario in US$ at 1990 prices and PPP: as the WEO projections are in US dollars at 1995 and PPP, the two series were not readily comparable. However, the WEO projects a slower growth rate for the period 2000-2030 (3.2% in the

first decade, 3% in the second and 2.7% in the third) than any of the other two. The A1B scenario grows at over 3.5% until 2040 and then slows down to around 2.7%; the A1T scenario has a slightly slower growth in the first period but continues growing at 2.9% in the last decade considered. Average per capita incomes in the WEO case grow about 77% from 2000 to 2030, while in the A1B and A1T scenario they grow 117% and respectively 120% over the same period. Clearly, these average global values hide very different growth rates at a regional level: in scenario A1B OECD's GDP grows to 2.6 times its 2000 value, Annex 1 countries GDP grew to three times its initial value and the non-Annex 1 countries GDP grew by 9.3 times! In scenario A1T the performances are a bit higher for all areas. As a result of this strong economic growth, the income gap between developed and developing countries is reduced considerably.

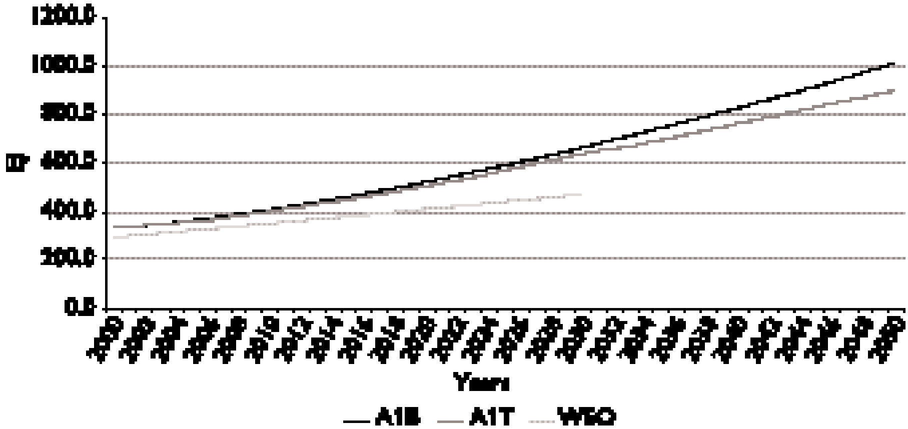
Total primary energy supply and total final consumption trends are shown in Figures A.II.3 and A.II.4. The two SRES scenarios clearly show a much higher trajectory, with a more rapid growth than the WEO scenario. Total primary energy demand in the A1B scenario increases in aggregate terms at a rate between 2 and 2.7% over the 1990-2050 period while the A1T scenario has growth rates between 1.7 and 2.7% (the lower rates are towards the last decade). The high growth in per capita incomes, especially in the developing world that characterizes these two scenarios is the main driver behind this robust growth in demand. Scenario A1T, however, has a lower growth than its A1B companion, and shows a clear divergence from that after 2030.

Figure A.II.3 Total Primary Energy Supply Projections



Source: Elaboration on data from SRES and IEA's WEO - 2002.

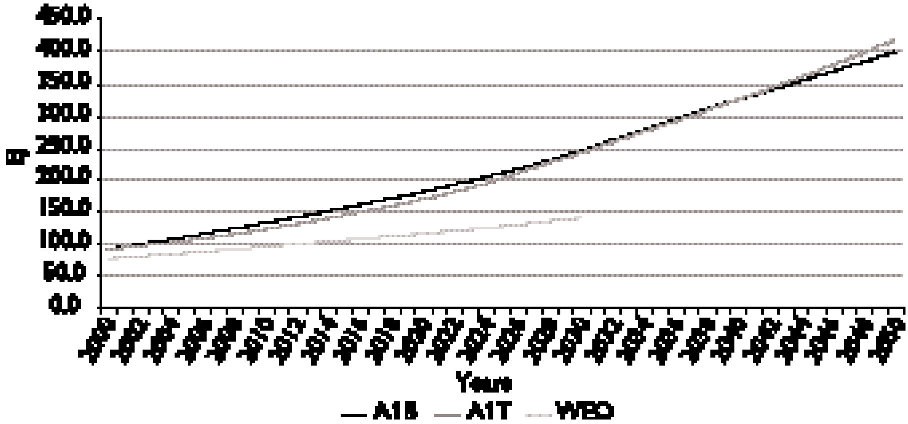
Figure A.II.4 Total Final Energy Consumption



Source: Elaboration on data from SRES and IEA's WEO - 2002.

Figure A.II.5 shows total final energy for the transport sector in the three scenarios. Again, the two SRES scenarios have a higher trajectory than the WEO, largely due to a faster expanding demand for transport services by the developing countries. In this case, however, consumption grows faster in the A1T case, especially after 2040, due to its higher GDP rate of growth.

Figure A.II.5 Transport Energy Consumption



Source: Elaboration on data from SRES and IEA's WEO - 2002.

Energy intensity of GDP falls in all three scenarios (see Tables A.II.4, A.II.5, A.II.6). The link between growth in income and growth in energy demand continues but, due to improving technology, newly industrialising countries will be in a position to use less energy than industrial countries did for similar income levels in the past. The trend is towards progressive

industrialisation of developing countries and rapid structural changes. Development of the services sector is strong in the A1B and A1T scenarios. Also, in general, capital turnover rate is high.

Table A.II.4 Selected Indicators for the MESSAGE A1B Scenario

Variable (unit of measure)	1990	2000	2010	2020	2030	2040	2050
Per capita income ratio (Annex-I/ Non-annex-I countries) – mer	16.15	14.19	9.54	6.44	4.30	3.20	2.77
Per capita income ratio (Annex-I/ Non-annex-I countries) - ppp	5.71	5.33	4.46	3.79	3.07	2.55	2.35
Per capita income, overall (10^3 US$/year at 1990 prices) - mer	3.97	4.37	5.50	7.42	10.88	15.85	20.83
Per capita income, overall (10^3 US$/yr- 1990 prices) - ppp	4.89	5.44	6.83	8.74	11.81	16.28	20.80
Energy intensity of GDP (10^6 J/US$) – mer	16.82	15.53	13.81	12.21	10.11	8.44	7.70
Energy intensity of GDP (10^6 J/US$) – ppp	13.65	12.46	11.12	10.36	9.32	8.21	7.71
Per capita energy (10^9 J)	66.80	67.84	76.00	90.51	110.10	133.72	160.45
Share of zero-carbon in primary energy (%)	17.52	16.63	19.79	22.80	25.72	30.20	37.74
Share of fossil fuels in transport (%)	97	91	81	74	63	57	52

Source: Values computed from SRES data. http://sres.ciesin.org/final_data.html

Table A.II.5 Selected Indicators for the MESSAGE A1T Scenario

Variable (unit of measure)	1990	2000	2010	2020	2030	2040	2050
Per capita income ratio (Annex-I/ Non-annex-I countries) - mer	16.15	14.16	10.29	6.21	4.24	3.32	2.75
Per capita income ratio (Annex-I/ Non-annex-I countries) -ppp	5.71	5.33	4.63	3.69	3.05	2.64	2.34
Per capita income, overall (10^3 US$/yr) - mer	3.97	4.38	5.34	7.48	11.16	15.87	21.50
Per capita income, overall (10^3 US$/yr) - ppp	4.89	5.46	6.64	8.83	12.06	16.29	21.42
Energy intensity of GDP (10^6 J/US$) - mer	16.82	15.52	13.94	11.39	9.31	7.52	6.48
Energy intensity of GDP (10^6 J/US$) - ppp	13.65	12.45	11.22	9.66	8.61	7.33	6.51
*Per capita energy (10^9 J) **	66.80	68.01	74.49	85.24	103.94	119.38	139.40
Share of zero-carbon in primary energy (%)	17.52	16.47	17.93	21.41	25.38	33.09	42.87
Share of oil products in transport (%)	96	89	82	72	60	48	37

Source: Values computed from SRES data. http://sres.ciesin.org/final_data.html

Table A.II.6 Selected Indicators for the WEO-2002 Reference Scenario

Variable (unit of measure)	1990	2000	2010	2020	2030
GDP (10^9 US$ at 1995 prices and ppp)	30865	41609	57174	76883	100160
Population – million	5226	6023	6778	7518	8196
Per capita income, (10^3 US$/yr) – ppp	5.91	6.91	8.43	10.23	12.22
Energy intensity of GDP (10^6 J/US$) - ppp	10.59	9.10	8.05	7.08	6.31
*Per capita energy (10^9 J) **	62.56	62.89	67.86	72.45	77.10
Share of zero-carbon in primary energy (%)	11.19	12.59	12.44	11.59	11.21
Share of oil products in transport (%)	95.4	95.2	95.4	95.6	95.8

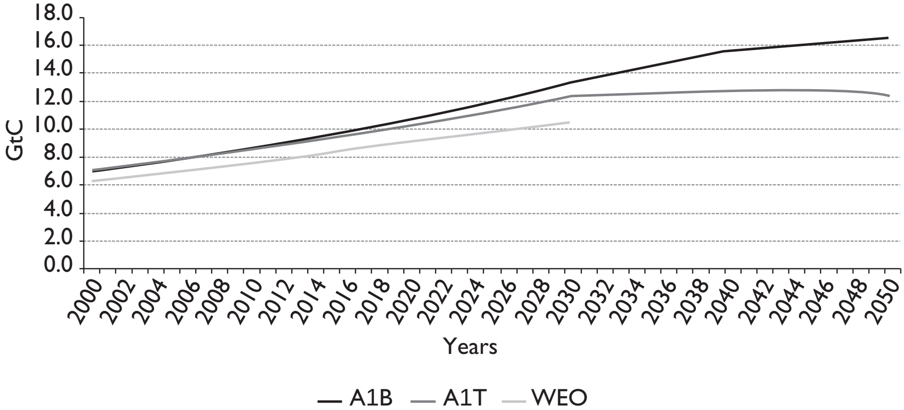
Source: Values computed from WEO-2002 data.

On energy intensity of GDP, the two SRES scenarios start diverging: for A1B this index falls to 74.8% of its 2000 value in 2030 and to 61.9% in 2050; for A1T the index falls more rapidly, to 69.1% by 2030 and to 52.2% by 2050. Energy intensity of income in the A1T scenario declines at an annual rate of 1.6% over the period, which is on the high end of the spectrum for rates historically attained. This decline would be slower in the first part of the period (-1.3%) and more rapid in the second part (-1.85%). Energy intensity of GDP in the WEO shows a dynamic not too different from that of A1T: by 2030, energy intensity is reduced to 69.3% of its 2000 value.

Per capita energy increases dramatically with respect to 2000 in the A1B scenario: 62.2% by 2030 and 136.5% (more than double) by 2050. The growth with respect to 2000 is slower for the A1T scenario: 52.8% by 2030 and 104.7% by 2050. In the WEO case, the increase is much slower: 22.6% by 2030.

Figure A.II.6 shows CO_2 emissions from fossil fuels burning in the three cases. Again, the WEO trajectory is the lowest of the three, due to the lower GDP growth assumptions. By 2030, the WEO reference world will continue along a linear trend, emits about 10.4 Gigatons of Carbon equivalent, while the A1T world emits 12.26 GtC and the A1B world emits 13.2 GtC. After 2030, the divergence between the A1B and the A1T scenario is clearer: while in the first case, emissions continue growing, although at a decreasing pace, in the A1T scenario clearly peak around 2045 and start bending down. The difference between the two is due to the different technology mix developed in the two cases. Scenario A1T develops more successfully non-carbon based energy technologies on the supply side, which tends to mitigate further energy supply shortages. Scenario A1B develops both carbon-based and non-carbon-based technologies, which compete in the marketplace.

Figure A.II.6 CO_2 Emissions



Source: Elaboration on data from SRES and IEA's WEO - 2002.

As can be seen from Tables A.II.4 and A.II.5, the share of zero carbon technologies in primary energy is almost the same by 2030 for both the A1B and the A1T scenario, at a little over 25%, while in the case of the WEO this share is much lower (11.2%). In the latter case, it is even worse with respect to the year 2000 level. The A1B scenario then attains by 2050 a 37.7% share, while the A1T reaches a 42.9% level.

If we look at the share of fossil fuel products in transport energy demand, in the A1B scenario this share declines gradually to about 43% by 2050, while in the A1T scenario it falls dramatically to 37%. On the other hand, in the WEO case the share of oil products in transport remains at about 95.5% throughout the period to 2030, the rest being mostly gas and electricity.

The A1B and A1T scenarios therefore represent a suitable basis for our analysis because of their fast technology and economic dynamic, which can accommodate dramatic changes like the ones envisioned in our SD Vision scenario. The A1T case seems particularly interesting as it already envisages a 43% share by 2050, although not as a policy target but as a result of other drivers, like technological change and strong environmental values held by the general population. Table A.II.7 describes the fuel mix characteristics of this scenario (as represented by IIASA's MESSAGE model) with some regional detail.

Tables A.II.8 to A.II.12 show in more detail the characteristics of the SD Vision scenario, at the global and regional level.

Table A.II.7 Characteristics of the A1T Scenario with the MESSAGE Model

World							
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	25.92	25.38	24.38	23.18	21.18	15.01	9.82
Oil	36.50	37.26	33.52	29.79	26.25	23.64	20.62
Gas	20.06	20.89	24.17	25.63	27.20	28.25	26.69
Nuclear	2.08	1.97	2.20	2.59	4.64	7.69	9.48
Biomass	13.09	10.94	10.78	11.50	12.17	13.45	15.12
Other renewables	2.36	3.56	4.95	7.32	8.56	11.95	18.27
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
of which zero-carbon	17.52	16.47	17.93	21.41	25.38	33.09	42.87
Oil as a % of total transport energy	95.86	88.83	82.46	71.78	60.47	47.57	37.30
Oil for transport in total oil %	49.86	51.88	59.03	61.50	65.53	64.25	61.81
OECD90							
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	23.9	19.4	17.7	14.7	10.9	4.7	1.6
Oil	45.4	44.8	39.9	33.4	27.4	23.0	17.9
Gas	20.7	24.2	28.2	32.4	34.5	32.9	29.6
Nuclear	3.7	3.7	4.0	4.4	9.3	18.0	21.9
Biomass	3.5	4.6	5.4	7.9	9.3	10.1	12.0
Other renewables	2.8	3.4	4.9	7.1	8.6	11.3	17.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	10.0	11.7	14.2	19.5	27.2	39.4	51.0
Oil as a % of total transport energy	98.0	92.2	88.7	74.5	62.1	53.6	46.2
Oil for transport in total oil %	56.4	57.8	70.5	80.9	89.5	98.4	107.2
REF							
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	26.7	25.2	18.9	20.5	20.3	16.9	10.6
Oil	29.3	26.8	22.8	21.6	17.8	15.0	11.4
Gas	38.4	42.1	52.8	48.8	47.3	46.7	49.2
Nuclear	1.4	1.5	1.3	1.4	4.3	9.1	9.6
Biomass	2.6	2.0	1.4	2.0	3.3	4.7	7.2
Other renewables	1.6	2.4	2.9	5.7	6.9	7.6	12.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	5.6	5.9	5.6	9.1	14.6	21.4	28.9
Oil as a % of total transport energy	82.2	63.3	55.3	44.4	33.3	19.9	14.4
Oil for transport in total oil %	31.2	37.9	41.4	38.9	41.6	34.4	39.8

Table A.II.7 (continued)

ASIA							
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	40.5	47.1	44.7	41.6	37.8	26.5	16.8
Oil	20.8	24.0	24.3	23.9	23.5	23.7	21.9
Gas	3.8	4.9	8.9	12.1	14.7	19.2	20.9
Nuclear	0.4	0.5	1.1	1.7	2.6	3.9	5.7
Biomass	33.0	20.8	17.0	14.2	13.5	15.2	17.8
Other renewables	1.5	2.7	4.0	6.5	8.0	11.4	16.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	34.9	23.9	22.0	22.4	24.0	30.6	40.3
Oil as a % of total transport energy	93.5	90.1	82.4	79.6	69.8	53.0	40.0
Oil for transport in total oil %	39.2	44.3	50.3	53.5	65.2	64.4	63.1
ALM							
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	9.5	7.2	7.9	6.9	7.5	7.8	6.7
Oil	41.5	46.2	41.6	37.9	32.5	26.8	23.2
Gas	16.4	20.4	24.4	26.8	30.3	30.4	25.9
Nuclear	0.2	0.1	0.9	1.7	2.8	3.9	5.8
Biomass	28.9	19.7	17.3	16.9	16.8	16.6	16.0
Other renewables	3.4	6.4	7.9	9.8	10.0	14.6	22.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	32.6	26.2	26.1	28.4	29.7	35.0	44.2
Oil as a % of total transport energy	98.9	90.8	77.0	67.6	55.5	41.6	31.6
Oil for transport in total oil %	53.4	48.9	50.0	49.5	49.3	46.2	40.0

Source: Elaboration on data from IIASA.

Table A.II. 8 Characteristics of the SD Vision Scenario

World							
	1990	2000	2010	2020	2030	2040	2050
Population (million)	5262	6117	6888	7617	8182	8531	8704
GNP/GDP (ppp) trillion (1990 prices)	26	33.4	43.0	64.9	94.9	131.2	173.2
Primary Energy – EJ							
Coal	91.10	105.6	118.3	135.6	153.5	128.0	99.3
Oil	128.3	155.0	165.8	178.5	193.0	191.4	181.3
Gas	70.5	86.9	123.2	157.3	206.9	244.2	267.1
Nuclear	7.3	8.2	11.4	18.1	39.1	75.3	114.5
Biomass	46	45.5	52.8	69.3	92.3	117.5	159.0
Other renewables	8.3	14.8	25.1	45.6	71.6	122.1	191.8
Total	351.5	416.0	496.6	604.3	756.3	878.5	1013.0
Energy for transport – EJ	66.7	90.5	119.7	155.8	217.7	277.7	344.4
Oil – EJ	64.0	80.4	98.4	111.3	130.6	131.2	132.4
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	25.9	25.4	23.8	22.4	20.3	14.6	9.8
Oil	36.5	37.3	33.4	29.5	25.5	21.8	17.9
Gas	20.1	20.9	24.8	26.0	27.4	27.8	26.4
Nuclear	2.1	2.0	2.3	3.0	5.2	8.6	11.3
Biomass	13.1	10.9	10.6	11.5	12.2	13.4	15.7
Other renewables	2.4	3.6	5.1	7.5	9.5	13.9	18.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	17.5	16.5	18.0	22.0	26.8	35.8	45.9
Transport share of primary energy %	19.0	21.8	24.1	25.8	28.8	31.6	34.0
Oil as a % of total transport energy	95.9	88.8	82.2	71.4	60.0	47.2	38.4
Oil for transport in total oil %	49.9	51.9	59.4	62.4	67.7	68.6	73.0
Emissions from fossil fuels GtC	5.78	6.90	7.98	9.19	10.68	10.57	9.99
Carbon storage GtC	0.00	0.01	0.03	0.27	0.79	1.65	2.58

Source: Elaboration on data from IIASA.

Table A.II.9 Characteristics of the SD Vision Scenario

OECD90							
	1990	2000	2010	2020	2030	2040	2050
Population (million)	859	919	965	1007	1043	1069	1081
GNP/GDP (ppp) trillion (1990 prices)	14	17.8	20.0	26.8	32.7	39.2	46.2
Primary Energy – EJ							
Coal	38.0	36.0	33.6	29.9	24.2	11.9	5.0
Oil	72.1	83.2	78.5	68.9	58.9	49.2	38.9
Gas	32.9	44.9	58.2	68.0	76.9	75.4	77.1
Nuclear	5.9	6.8	7.9	10.3	21.9	39.0	51.0
Biomass	5.6	8.6	10.7	17.1	20.6	24.4	31.7
Other renewables	4.4	6.3	10.3	15.4	20.3	29.3	40.6
Total	158.9	185.8	199.2	209.6	222.8	229.2	244.4
Energy for transport – EJ	41.5	52.2	63.2	76.0	88.1	90.9	96.8
Oil – EJ	40.7	48.1	55.8	56.2	54.2	47.8	43.3
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	23.9	19.4	16.9	14.2	10.9	5.2	2.1
Oil	45.4	44.8	39.4	32.9	26.4	21.5	15.9
Gas	20.7	24.2	29.2	32.4	34.5	32.9	31.6
Nuclear	3.7	3.7	4.0	4.9	9.8	17.0	20.9
Biomass	3.5	4.6	5.4	8.2	9.3	10.6	13.0
Other renewables	2.8	3.4	5.2	7.3	9.1	12.8	16.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	10.0	11.7	14.5	20.5	28.2	40.4	50.5
Transport share of primary energy %	26.1	28.1	31.8	36.3	39.5	39.7	39.6
Oil as a % of total transport energy	98.0	92.2	88.2	74.0	61.6	52.6	44.7
Oil for transport in total oil %	56.4	57.8	71.0	81.6	92.1	97.2	111.1
Emissions from fossil fuels GtC	2.80	3.14	3.19	3.07	2.88	2.37	2.03
Carbon storage GtC	0.00	0.01	0.03	0.12	0.26	0.43	0.55

Source: Elaboration on data from IIASA.

Table A.II.10 Characteristics of the SD Vision Scenario

REF							
	1990	2000	2010	2020	2030	2040	2050
Population (million)	413	419	427	433	435	433	423
GNP/GDP (ppp) trillion (1990 prices)	2.6	2.2	2.5	3.6	5.7	8.8	11.5
Primary Energy - EJ							
Coal	18.6	13.7	10.5	12.3	15.5	14.3	10.2
Oil	20.4	14.6	12.7	13.3	13.6	12.2	10.0
Gas	26.7	22.9	29.3	30.9	36.9	39.9	41.9
Nuclear	1.0	0.8	0.7	1.2	3.6	8.4	10.7
Biomass	1.8	1.1	0.8	1.6	3.0	4.5	7.3
Other renewables	1.1	1.3	1.6	3.9	5.8	7.9	12.0
Total	69.6	54.4	55.6	63.2	78.5	87.2	92.2
Energy for transport - EJ	7.8	8.7	9.5	12.0	17.5	22.6	29.0
Oil - EJ	6.4	5.5	5.2	5.2	5.5	4.5	4.8
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	26.7	25.2	18.9	19.5	19.8	16.4	11.1
Oil	29.3	26.8	22.8	21.1	17.3	14.0	10.9
Gas	38.4	42.1	52.8	48.8	47.1	45.7	45.4
Nuclear	1.4	1.5	1.3	1.9	4.6	9.6	11.6
Biomass	2.6	2.0	1.4	2.5	3.8	5.2	8.0
Other renewables	1.6	2.4	2.9	6.2	7.4	9.1	13.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	5.6	5.9	5.6	10.6	15.8	23.9	32.6
Transport share of primary energy %	11.1	16.0	17.1	18.9	22.2	25.9	31.5
Oil as a % of total transport energy	82.2	63.3	55.3	43.9	31.3	19.9	16.4
Oil for transport in total oil %	31.2	37.9	41.4	39.3	40.2	36.9	47.4
Emissions from fossil fuels GtC	1.3	1.0	1.0	1.0	1.2	1.2	1.1
Carbon storage GtC	0.00	0.00	0.00	0.03	0.07	0.14	0.28

Source: Elaboration on data from IIASA.

Table A.II.11 Characteristics of the SD Vision Scenario

ASIA							
	1990	2000	2010	2020	2030	2040	2050
Population (million)	2798	3261	3620	3937	4147	4238	4220
GNP/GDP (ppp) trillion (1990 prices)	5.3	8.3	12.1	20.5	32.6	47.0	63.0
Primary Energy - EJ							
Coal	29.8	51.0	67.1	84.8	101.1	84.7	67.1
Oil	15.3	26.0	36.7	48.9	63.0	67.8	65.6
Gas	2.8	5.3	13.5	24.9	39.4	58.1	74.8
Nuclear	0.3	0.5	1.9	4.4	8.5	17.4	30.9
Biomass	24.3	22.5	25.6	29.4	38.4	48.7	68.7
Other renewables	1.1	2.9	6.0	13.9	24.7	44.4	68.9
Total	73.6	108.2	150.8	206.4	275.1	321.0	376.0
Energy for transport - EJ	6.41	12.78	22.38	33.18	60.35	92.43	130.20
Oil - EJ	6.00	11.51	18.45	26.42	42.12	49.01	54.65
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	40.5	47.1	44.5	41.1	36.8	26.5	17.8
Oil	20.8	24.0	24.3	23.7	22.9	21.2	17.4
Gas	3.8	4.9	8.9	12.1	14.3	18.2	19.9
Nuclear	0.4	0.5	1.3	2.1	3.1	5.4	8.2
Biomass	33.0	20.8	17.0	14.2	14.0	15.2	18.3
Other renewables	1.5	2.7	4.0	6.8	9.0	13.9	18.3
Total	100.0	100.0	100.0	100.0	100.0	100.5	100.0
of which zero-carbon	34.9	23.9	22.2	23.1	26.0	34.6	44.8
Transport share of primary energy %	8.7	11.8	14.8	16.1	21.9	28.8	34.6
Oil as a % of total transport energy	93.5	90.1	82.4	79.6	69.8	53.0	42.0
Oil for transport in total oil %	39.2	44.3	50.3	54.0	66.9	72.3	83.3
Emissions from fossil fuels GtC	1.10	1.88	2.62	3.48	4.38	4.33	4.09
Carbon storage GtC	0.00	0.00	0.00	0.07	0.31	0.65	1.02

Source: Elaboration on data from IIASA.

Table A.II.12 Characteristics of the SD Vision Scenario

ALM							
	1990	2000	2010	2020	2030	2040	2050
Population (million)	1192	1519	1875	2241	2557	2791	2980
GNP/GDP (ppp) trillion (1990 prices)	3.8	5.1	7.4	12.7	21.2	33.2	49.2
Primary Energy - EJ							
Coal	4.7	4.9	7.2	8.6	12.6	17.0	17.0
Oil	20.5	31.2	37.9	47.4	57.5	62.2	66.7
Gas	8.1	13.8	22.2	33.5	53.7	70.9	73.3
Nuclear	0.1	0.1	0.9	2.2	5.1	10.6	21.9
Biomass	14.3	13.3	15.7	21.1	30.3	39.9	51.2
Other renewables	1.7	4.3	7.2	12.3	20.8	40.6	70.3
Total	49.4	67.6	91.1	125.2	180.0	241.3	300.4
Energy for transport - EJ	11.1	16.8	24.6	34.7	51.8	71.8	88.4
Oil - EJ	11.0	15.3	18.9	23.5	28.8	29.9	29.7
	1990	2000	2010	2020	2030	2040	2050
Primary Energy - % shares							
Coal	9.5	7.2	7.9	6.9	7.0	7.1	5.7
Oil	41.5	46.2	41.6	37.9	32.0	25.8	22.2
Gas	16.4	20.4	24.4	26.8	29.8	29.4	24.4
Nuclear	0.2	0.1	0.9	1.7	2.8	4.4	7.3
Biomass	28.9	19.7	17.3	16.9	16.8	16.6	17.0
Other renewables	3.4	6.4	7.9	9.8	11.5	16.8	23.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
of which zero-carbon	32.6	26.2	26.1	28.4	31.2	37.8	47.7
Transport share of primary energy %	22.4	24.9	27.0	27.7	28.8	29.8	29.4
Oil as a % of total transport energy	98.9	90.8	77.0	67.6	55.5	41.6	33.6
Oil for transport in total oil %	53.4	48.9	50.0	49.5	50.0	48.0	44.5
Emissions from fossil fuels GtC	0.62	0.91	1.22	1.60	2.20	2.66	2.78
Carbon storage GtC	0.00	0.00	0.00	0.05	0.15	0.43	0.72

Source: Elaboration on data from IIASA.

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GLOSSARY

Abbreviations and acronyms

ACUNU: American Council for the United Nations University
ALM: Africa, Latin America and Middle East
ASIA: Asia, except Middle East
Cap: per capita
CO_2: carbon dioxide
CDM: Clean Development Mechanisms
GHG: green-house gases
GSG: Global Scenario Group
IIASA: International Institute for Applied Systems Analysis
IPCC: Intergovernmental Panel on Climate Change
NOx: nitrogen oxides
Ppm: parts per million
Ppmv: parts per million volume
PPP: purchasing power parities
REF: Russia, Eastern Europe and Former Soviet republics
R&D: Research and Development
SD: Sustainable development
SEI: Stockholm Environment Institute
SOx: sulphur oxides
SRES : Special Report on Emissions Scenarios
TPES : total primary energy supply
UKDTI : United Kingdom Department of Trade and Industry
UNFCCC: United Nations Framework Convention on Climate Change
WBCSD: World Business Council for Sustainable Development
WGIII: Working Group 3 of the IPCC

Units of measure

Bbl : billion barrels of oil
EJ: exa-Joule or 10^{18} Joules
GtC: Giga (10^9) tonnes of carbon
Gtoe: Giga (10^9) tonnes of oil equivalent
J: Joule
Mer: market exchange rates
Mtoe: million tonnes of oil equivalent
Tcm: trillion cubic meters

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